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NDE for Realising Better Quality of Life in the Context of INDIA - An Emerging Economy

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Abstract Science and technology is an essential ingredient of the progress in modern society. Measurements enable action and actions enable results. Non-Destructive Evaluation (NDE) - the science and technology of measurements without affecting the properties and performance of the test object is an interdisciplinary domain area of high significance for ensuring quality, productivity and safety thus enabling better quality of life to the inhabitants on this planet. The test object can be material, component, plant, earth, environment etc. Total quality management, total productivity management, concurrent engineering and many other essential ingredients of success in plant engineering and manufacturing industry are dependent on NDE for success and good returns on investments.

Introduction

The quality of life available to the majority of citizens of any country is a direct indicator of its state of economy. The state of a nation's economy is reflected by its growth in the major industrial sectors categorised normally as strategic, core, infrastructure and consumer. It is imperative to monitor and increase the growth in these sectors for an overall successful economy of a nation and superior quality of life for its citizens therein. These sectors are also in the forefront of global competitiveness and thus need the highest attention and priority to boost exports and global marketing. It is thus essential to implement and build a system to implement quality in the processes, practices and products related to all industrial sectors in general and the above mentioned sectors in particular. This could be achieved by adopting the concept of total quality management for as many functions of relevance as possible. While there are a number of factors which go into the implementation of total quality management in any system, we would be confining our discussions to the specific role of nondestructive evaluation (NDE) in this regard and its indirect impact on the quality of life for the people of any nation.

India has a rich heritage of quality. The Taj Mahal at Agra, the Iron Pillar at Delhi, Investment Cast Bronze Icons and Idols and Wootz Swords are outstanding examples that highlight the Indian traditions of artisanship and technology. From the Iron Pillar to the atomic, space and information age, India has matured as a nation endowed with expertise in relevant and critical technologies. Ever since India attained independence in 1947, there has been a sustained

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and comprehensive approach to the development of industries for production of precision, strategic and heavy components. Self reliance is the watchword in all the areas of the national progress, particularly in the strategic and core sectors. In order to achieve consistent success in all the industrial and other ventures, India has nurtured the crucial role of NDE for achieving quality in all sectors. NDE is now being practiced widely in the industries of India to improve the quality of the products and services. Greater awareness has been generated among the industries by systematic education, training and other means of imparting knowledge. The increased awareness of the use of NDE for quality assurance has also led to a rapid increase in the market for NDE equipment and consumables. The synergistic alliance between the scientists and the manufacturers has opened up new avenues for technology and technical collaborations. Cross fertilization between the Indian and foreign manufacturers as well as NDE specialists is paving the way for greater techno-commercial flow of ideas and information. India is pursuing R& D in various aspects of NDE with a comprehensive approach to attain highest levels of quality in components, structures and products, keeping in mind the cost effectiveness.

The paper highlights the successful use of NDE in some of the industrial sectors mentioned earlier with specific reference to India. The success achieved in the field of NDE science and technology for solving many challenging problems requiring innovative methodologies, sensors and instrumentation is attributed to synergistic approach adopted in pooling the expertise and experience available in strategic and core sectors, academic and research institutes. Two most important programmes where such an approach provided rich dividends are the life extension programme of defence aircrafts and helicopters for Indian Air Force and the mission programme on Intelligent Processing of Materials (IPM) of the Department of Science and Technology (DST). The current status of NDE Science and technology is reviewed along with the role of training and certification. In the end, the pushers, pullers and gaps in NDE science and technology are identified and discussed as a prelude to more effective thrust on the directions for the future with special reference to emerging economies which attach their dreams of better quality of life to its citizens through science and technology.

NDE in the Strategic Sectors

The strategic sectors of defence, space, electronics, information technology and atomic energy have a major role to play as they are the forerunners for developing, adopting and implementing the most recent and advanced technologies as well as modern concepts and philosophies such as Total Quality Management (TQM). This is not of a specific reference to an emerging economy but to the world as a whole. This conclusion originates from the fact that these sectors demand extremely rigid and stringent quality requirements. It would be no exaggeration to say that the developments in the strategic sectors in view of their mission related projects have benefited the other sectors to a large extent by way of availability of modern technology and expertise for solution to some of their problems. The strategic sectors in India have taken early initiative for broad based research program to build expertise in NDE science and technology for meeting the national needs and have also built a strong base to have an indigenous expertise suitable for specific applications. These sectors also strive to spread the in-house developed expertise and technology to the needy Indian industry to solve many challenging problems. Immense opportunities exist to use this reservoir of expertise and experience for achieving cost effective quality requirements in small, medium and large industries

The earliest initiative for utilizing NDE techniques for producing quality components in the Indian defence and railway industry was taken by the British during their ruling period. However, modern day NDE science and technology took roots in India, thanks to the indigenous large scale programme of the Department of Atomic energy (DAE). The contributions of DAE to NDE are based on comprehensive R & D and also through its interactions with the industries who are responsible for making components with stringent performance related quality requirements. A few examples of the successful implementation of NDE science and technology in the early years of DAE programmes are the fabrication of first half fuel charge of Canada-India Reactor for Utility and Services (CIRUS) and Rajasthan Atomic Power Station (RAPS), pressure tubes, calandria tubes, end shields, pressure retaining components and piping of CIRUS and RAPS. All these components have performed well and are indeed comparable or better than anywhere else in the world. The successful implementation of extension of design life of CIRUS is a direct reflection of this. A wide variety of technologies have been developed for the life extension of Boiling Water Reactors (BWRs) including the challenging task of inspection of critical components by developing remotely operated underwater devices and NDE procedures. The ultrasonic Synthetic Aperture Focussing Technique (SAFT) has been specifically developed for inspection of nozzle welds, reactor pressure vessels with high sensitivity and reliability. The pressurised heavy water reactors (PHWRs) are the mainstay of the Indian nuclear power programme and significant effort has been made for incorporating and implementing NDE at all possible stages of its design, manufacture, erection, commissioning, operation and maintenance.

The Department of Atomic Energy in India has also initiated a comprehensive integrated sensor, instrumentation and software approach for significant breakthroughs. Sensors constitute the important component in any nondestructive evaluation regime. Relevance of the proper sensors for a given purpose and environment can not be overlooked, as the information extracted and the ultimate evaluation capability depends on the choice of sensor or complementary sensors and associated instrumentation. At Indira Gandhi Centre for Atomic Research (IGCAR), a large number of non destructive test techniques are used for material characterisation. All the techniques are dependent very largely on the use of the best possible sensors to obtain the desired results. In order to improve the performance of a measurement method as well as to acquire the capability to design and develop sensors in-house, a number of programmes have been undertaken. The cost of the various sensors for different techniques are significantly high and the indigenous developments have resulted in considerable cost savings and also provided vital input for solving critical problems in DAE and other strategic and core industries.

A new optical technique has been developed for detection of defects in ferromagnetic materials using an indigenously developed sensor consisting of ferro fluid emulsion. This new flux leakage sensor consists of monodispersed ferro fluid confined between two thin transparent sheets or in cuvette and a white light source for illumination. By employing ferro fluid droplets of suitable size and surfactant concentration and mounting the cell on the test specimen surface, one can detect the region where the defect is located in the test specimen by visually observing a colour change in the ferro fluid sensor in the vicinity of the defects. By employing a spectrophotometer to measure the shift in the wavelength of the light source (a function of intensity of leaking magnetic flux), detection and quantitative sizing of defects is achieved.

Special miniature eddy current sensors have been developed and supplied to the defence and space industry for strategic applications. A large number of sensors have been developed and supplied for the in-service inspection of heat exchangers. Radiation resistant eddy current sensors have been designed and fabricated for post-irradiation examination of irradiated fuel pins in the radioactive hot cells. Very recently an eddy current array probe system consisting of eight rectangular probes has been designed and fabricated for on-line detection of metallic particles in insulator boards used in electrical transformers and is undergoing field trials in the plant for its final adoption.

A special focussed sensor for detection of extremely fine scratch like defects of the order of 25-50 microns deep has also been designed and practically applied successfully. A tandem sensor for use with phased array eddy current testing (PAECT) systems has been designed and developed. This sensor performs with improved reliability over conventional PAEC sensors by eliminating the insensitive dead zones present in them. A special eddy current sensor for the inspection of ferromagnetic tubes has been designed and developed using the concept of partial saturation involving the use of high strength permanent magnets in specific configurations. Sensors have also been developed for the remote field eddy current technique which has wide applications for inspection of ferromagnetic tubes.

A split coil sensor has been developed for the testing of steel wire ropes which are extensively used in various industries such as mining, steel, shipping, petrochemical, heavy industries, off-shore drilling, etc. These ropes have to be periodically inspected to detect defects and damages resulting from its continuous use, corrosion, ageing, etc. This new sensor overcomes some of the drawbacks of existing sensors such as sensitivity variation with speed, residual magnetism due to use of permanent magnets and difficulty in on-line inspection.

Use of the principle of acoustic resonance as a technique for leak detection has been established. In this technique, an exciter produces a base wave and is transmitted through the tube and the signal at the other end is sensed by the receiver. The signature of the received signal is analysed by digital signal processing techniques. The presence of a leak creates acoustic disturbances on the received signal and changes the spectral content. The technique is capable of detecting leaks of the order of 10^{-3} to 10^{-4} std cc/sec even in the presence of high external noise.

The magnetic Barkhausen noise (MBN) technique is a novel NDE technique for characterising microstructure and stresses in components of ferromagnetic materials by monitoring the emission which occur during the cyclic magnetisation of the component. A large number of MBN sensors have been designed to achieve the desired detection sensitivity as well as to conform to the requirements of the component shape for amenable access and measurements.

In order to ensure reliable, safe and economic performance of plant components, DAE has always laid emphasis on synergising the design and the NDE of components. In design, the parameters causing failures is usually specified in terms of stress, but it could very well be specified in terms of the characteristics of the flaw. In the case of coolant channels of pressurised heavy water reactors, the loss of thickness of pressure tubes, change in annular gap between pressure tube and calandria tube, and hydrogen concentration in metal matrix can all be considered as flaws. Effective application of such approaches requires quantitative NDE data on such parameters as well as means to determine the available margin before it reaches a critical level. Towards this, Bhabha Atomic Research Centre Channel Inspection System (BARCIS) has been developed which has the following capabilities: ultrasonic testing for measuring thickness and detection of flaws in longitudinal and circumferential directions in pressure tubes, eddy current testing for detection of location and tilt of garter springs, estimation of annular gap between pressure tube and calandria tube, flaws in longitudinal and circumferential directions on inner surface of the pressure tube and inclinometer based sag measurement of the pressure tube. This approach has also been extensively adopted for residual life assessment of nuclear plant components, assessment of core shrouds of TAPS, development of leak before break methodology etc.

To meet the challenging requirements of the strategic sector, due emphasis has been given for building expertise in development of integrated systems and validated advanced testing procedures. For critical applications requiring higher sensitivity of detection and complete characterisation of defects, advanced concepts like signal analysis, image processing, artificial neural networks, data fusion, computer aided visualisation etc. have been successfully adopted. Some of the NDE systems developed in the Department of Atomic Energy include: multichannel acoustic emission system, ultrasonic systems for flaw detection and precise transit time measurements with an accuracy of 0.1 ns, magnetic flux leakage measurement systems, image processing and analysis systems, remote field eddy current testing system etc. A finite element based model has been developed for probe design and optimisation of parameters for eddy current testing of axi-symmetric components and the model has been successfully employed for a variety of critical applications. An approach with advanced ultrasonic signal analysis and pattern recognition methodologies has been developed for detection of defects of the order of 2% thickness in noisy weldments of stainless steel and maraging steel and also fine defects in end plug welds of thin walled zircaloy-2 nuclear fuel pins of pressurised heavy water reactors. Systematic procedures based on artificial neural network analysis of eddy current signals have been developed for detection with high sensitivity and comprehensive characterisation of defects with respect to size, type and location in austenitic stainless steel. As part of comprehensive quality evaluation programme for critical tube to tube sheet weld joints of steam generators of a 500 MWe prototype fast breeder reactor (PFBR), microfocal radiographic procedure with a sensitivity for detection of pores of 30 microns have been developed and employed. Magnetic Barkhausen noise and X-ray diffraction based methods for residual stress measurements have been developed for assessment of fabrication quality and inservice degradation for components such as ferritic steel tube to tube sheet weld joints of steam generators, steam turbine blades etc. Extensive efforts have also been made for characterisation of microstructures in various materials using ultrasonic and magnetic Barkhausen noise techniques.

Extensive use of NDE is also made in achieving improved reliability of space components and structures since the space missions succeed if and only if their components perform as expected. Their complex characteristics demand different NDE techniques for both ensuring and improving reliability of their performance. Liquid propulsion is used both in launch vehicles and spacecrafts. Solid and cryogenic propulsion is used in launch vehicles. Different NDE techniques employed in liquid propulsion include microfocus radiography, immersion ultrasonic testing, penetrant testing, holography, etc. Those used in solid propulsion are high energy X-radiography, neutron radiography, thermography, low frequency ultrasonic testing, and acoustic emission. In addition to the above the other components and structures which form a significant part of a satellite/space launch vehicle are also extensively inspected using NDE to assure their quality and certify their reliability during and in-flight.

The Indian defence industry for example has implemented the use of NDE science and technology very effectively in the quality control of their armament products and missiles at all stages from design to mass production and subsequent storage of armaments. Faced by the challenges of reduced funding, foreign embargoes, etc, The Indian armament industry has risen to the occasion and successfully produced quality products by emphasis on use of NDE. Almost all the major NDE techniques are used for assessing the quality of the materials and products with the ultimate objective of customer satisfaction. On similar lines, the manufacturers of aircrafts and ships for the defence sector have indigenously developed a large number of technologies and methodologies for quality improvement and implemented them at their respective places.

A very important indigenous venture has been the development of NDE techniques, methodologies and procedures for the life extension of the aircrafts of the Air force. In the Indian context, most of the aircrafts and helicopters are of foreign origin and some of them have reached the design life and need extension of life through systematic evaluation and replacement and/or repair of some of the components if needed. It is also the experience that, many a time, the cost of the spares and accessories for replacement is prohibitively expensive. Additionally, the cost for extending the life of these aircrafts and helicopters after carrying out the required checks by the foreign manufacturers is very high and sometimes, the aircrafts are to be flown to the manufacturers for this purpose. There is also tremendous reluctance on the part of the manufacturers to transfer the technology related to life extension to our full satisfaction, and even if it is agreed to do so, the charges demanded are not commensurate with the technology/services offered. In view of this, it has been decided judiciously and rightly that suitable mechanism should be evolved for implementation of the life extension program with the indigenous technological expertise, and based on the design and operational experience gained so far, the general philosophy followed by world over for life extension, the information available in open literature and finally drawing analogy from the programs of the life extension of plants and components of other strategic, core and infrastructural sectors.

The approach followed for this purpose involved formation of a Task Group for each specific life extension activity, consisting of specialists from users, national laboratories and Government academic institutes. The primary purpose of these Task Groups was to identify the structural components to be inspected for life extension, based on the design, stress analysis, operational experience, fracture mechanics concepts, corrosion and fatigue damage analysis, ageing degradation etc. Many a time, additional components are to be inspected, in addition to those which are inspected routinely within the design specified life and as per the maintenance manuals. For inspection of these additional components, procedures and standards are not available for inspection. It is the responsibility of the NDT specialists in the Task Group to develop suitable procedures and standards for inspection of these additional components, first in laboratory using the components taken out from the Category E (damaged and unserviceable) aircrafts and helicopters and subsequently adopting the procedures for inspection of the actual components, In this connection, Indira Gandhi Centre for Atomic Research (IGCAR) has immensely contributed towards development and demonstration of the procedures using the extensive expertise and facilities available at IGCAR in the area of NDT. We have also taken a conscious decision to transfer the complete technology related to the procedures developed to the users and also to impart required training to the personnel of user agencies who can carry out the inspections routinely. The Task Groups also review NDT procedures already available for inspection of various components and suitable modifications are recommended wherever necessary for improving the sensitivity and reliability, an essential approach for ensuring reliable performance of the ageing fleet with higher confidence level and extending their life. To meet many challenging inspection problems, in addition to conventional NDT techniques, advanced techniques and procedures such as real time radiography, infrared thermography, X-ray diffraction, signal and image processing methodologies, knowledge based systems etc. have been developed and applied for specific cases, with the help of multi disciplinary Task Groups in an effective and expeditious manner and by synergistic exploitation of national expertise. Two important components for which systematic NDE procedures have been developed as part of life extension programme are landing gears of aircrafts and tail rotor blades of helicopters, are discussed below as illustrative examples.

As part of the study to extend the life of landing gears (LG) of aircrafts, residual stress analysis at a few select locations using the X-ray diffraction (XRD) technique was carried out on a number of LGs including new, used (for varied number of landings), and rejuvenated. It was observed that the top surface of a new LG had compressive stresses of the order of 500 - 600 MPa. The used LGs showed gradual changeover from the original compressive stress of 500 - 600 MPa to a tensile stress of about 100 MPa, with increase in the number of landings. In the case of a LG which had seen maximum landings, the residual stress measurements in the depth direction showed a gradual changeover from the tensile stress on the surface to 550 MPa compressive stress at a depth of 300 microns. The presence of tensile stresses on the top surface of the used LG indicates redistribution of the residual stresses due to accumulation of fatigue damage on the surface. All these measurements have been made at different locations prone to fatigue damage (based on the FEM design analysis). The portable XRD system employed in the present study enables in-situ measurements on the aircrafts. The extent of redistribution of the residual stresses at different regions of the landing gear could be well correlated to the different stress levels experienced and as indicated in the stress album. These studies also have been extended to qualify the rejuvenation process employed for extending the life of the landing gears. The rejuvenated LGs showed compressive stresses of the order of 350 to 400 MPa. These stress levels are adequate as the rejuvenated landing gears are expected to be used for only two thirds of the landings employed in the case of a new landing gear, prior to its rejuvenation. The results clearly established the use of residual stress measurements for evaluating the LGs based on the extent of fatigue damage, recommending the remaining life as well as their life extension and to qualify the rejuvenation process.

Tail rotor blades of helicopters have a service life of the order of 1000 to 1500 hours after which they are normally withdrawn from service. However, in many cases it has been observed that even after the expiry of the life, the blades are found to be sound with no external indications of geometrical deterioration or material failure, indicating the possibility for extension of the life of these blades. Hence, NDE procedures have been developed and applied for thorough inspection of the used blades to ensure their integrity and thereby recommend the extension of their life. A typical tail rotor blade of an helicopter contains steel brackets for mounting, a spar of aluminum alloy, honeycomb structures with fiberglass cover and ribs of aluminum alloy. Due to the varied type of materials used such as metals, composites, adhesively bonded regions, no single NDE technique is capable of inspecting the blade as a whole. Thus, complementary NDE techniques have been applied. The blade has been zoned into various regions based on their criticality and the suitability of NDE techniques. Ultrasonic testing for the examination of the metallic portions including the area around the bolts, real time radioscopy for the metallic, honey comb and composite regions and thermal imaging for adhesively bonded regions have been employed. Image processing techniques such as integration, spatial filtering and chopping were used on the raw real time radioscopy and thermal images to improve the signal to noise ratio.

Additionally, we have also carried out quality evaluation and failure analysis of a few critical components like compressor discs and blades of aeroengines, wheels, main gear box bolts and fuel tanks of aircrafts and helicopters to establish the root cause analysis and recommend suitable measures for avoiding recurrence of such failures. The techniques used in the investigations included visual examination, micro focal radiography, stereo-microscopy, hardness measurements, optical and scanning electron microscopy. The failure investigations also helped in framing recommendations with regard to implementation of improved NDE techniques for these components for effective monitoring of the component integrity.

In the context of NDE, the goals of life extension program to be pursued further include: (1) State of art NDT capabilities with respect to trained personnel, infrastructure and instruments, (2) Safety, reliability and economy, (3) Technical and scientific excellence, (4) To undertake challenging programs that extend limits of technical accomplishments and scientific innovation and (5) Creating suitable research environment, team work, etc. The research and development studies should include (a) Flight structural integrity, (b) NDE for evaluation of metallic and composite materials, (c) detection and quantitative characterisation of cracks, corrosion, microstructural degradation and residual stress, d) material and mechanical property data base, on-line flight monitoring by employing strain gauge, temperature monitoring devices, acoustic emission technique, smart sensors etc.

NDE in the Core Sectors

In any emerging economy like India, the power, steel, aluminium and oil/petrochemical sectors can be considered as the core sectors and they form a large part of the entire economy thus influencing the overall economical growth of the nation. It thus becomes important to evaluate the performance of these sectors in a comprehensive manner for their proper and sustained growth at all times.

The power sector is one of the most important of the core sector industries since power is the lifeline of any industry. To ensure efficient power generation and distribution and also to keep the power plants running without unplanned shutdowns, it is essential to ensure the quality of all the components and structures which go into the building of a power plant. In addition to structural integrity criterion, cost reduction is also one of the driving forces to develop newer technologies for improved efficiency, material economy and life extension. The Indian power sector with special reference to the manufacturers of power plant components use a wide variety of NDE techniques in their quality assurance procedures which include both conventional and advanced techniques. As in most other industries, NDE is incorporated from the design stage itself and also spelt out as part of the purchase specifications of raw materials. NDE is built into the manufacturing process by giving it a special process status, certified to ISO

9001. This sector has also taken a large initiative towards proper training and human resources development for more effective implementation of quality procedure through NDE utilisation. On identical lines, the power generation sector has taken large strides in using NDE for condition monitoring and in-service inspection in power plants. Health assessments on a number of plants have shown number of crackings, structural degradation, swelling and embrittlement in elevated temperature components in turbines and boilers specifically. NDE ensures structural integrity and also provides a kind of baseline/reference data for future use and analysis.

To match the quality requirements of the industries, the Indian steel industry which is the major supplier has also taken a lead in producing quality products and make extensive use of NDE to achieve the same. The steel industry has installed on-line automated facilities consisting of magnetic particle, ultrasonic and eddy current techniques for inspection of rails, axles and wheels.

The aluminium manufacturing industry also has made extensive use of NDE especially in the continued reliable operation of their plants by effective condition monitoring of the various components. In a novel application, NDE has been utilised as a tool for continuous process monitoring and control of aluminium reduction cells. Alumina feed control is of utmost importance for smooth and efficient operation of electrolytic cells. A unique system based on resistance tracking with sophisticated algorithms and computer control has been efficiently used to control the feed rate.

NDE for Infrastructure

NDE science and technology has made significant contributions to the quality assurance and condition monitoring for Indian Railways which is one of the largest transportation network in the world and forms the backbone of the Indian economy and infrastructural development. The Indian Railways possesses a large fleet of locomotives, coaches, wagons and a staggering 119724 bridges over a vast network of 62495 route kms. The Indian Railways adopts a two pronged strategy for ensuring the full service potential of the components without adversely affecting safety and consists of NDE before a component enters into service and continued periodic inspection at regular intervals. Almost all the commonly used NDE techniques are used extensively to achieve the objectives. Due to effective implementation of 100% ultrasonic testing of wheel sets (axles and discs), failures in service have been reduced by nearly 90%. Recognising the need for uniformity in testing procedure and application of acceptance criteria, they have formulated codes and procedures for various critical components. Similarly since most NDE equipment for railway applications are specific and tailor made, standards have been prepared for all NDE equipment to facilitate procurement and consistency in quality. Since NDE has emerged as an important quality control and safety management tool with a vast scope for further exploitation, the railways have identified tasks of immediate concern which include a more comprehensive ultrasonic examination of rails, measurement of residual stress in rail, rail welds and wheels, EMATs and acoustic emission for bridges and other structures, etc. Thus the Indian Railways has demonstrated the significant application of NDE in the infrastructure sector which contributes to the nation's economy.

NDE for Consumer Products

NDE is playing a significant role in a number of sectors including food, pharmaceuticals, chemical products and consumer goods, to ensure quality and brand status, particularly in the context of global competition. For example, ultrasonic velocity and attenuation parameters are extensively employed for assessment of the quality of fruits, meat (marbling) of live animals, oil etc. Extensive use of NDE is also made in the quality control of the packing material used for food products. The cosmetic and pharmaceutical industry use NDE to locate presence of undesirable foreign particles. Till recently, the use of NDE in these sectors in India was limited. With stiff competition due to the advent of multinationals and ensuring quality products with consistency, these industries are looking for introducing efficient NDE technologies.

Intelligent Processing of Materials

In the case of manufacturing industries, the specific demands for NDE are related to meeting the requirements of large production, high speed, large area scanning, repeated inspection of mass produced items, capability to adoption for divergent products, automation with flexibility etc. This has led to introduction of systems for automatic inspection and segregation of accepted/ rejected products through on-line NDT&E in these industries. A step made further in the direction of quality improvement in some of the industries is the adoption of concept of intelligent processing of materials (IPM) with the objective of not only on-line assessment but also control of quality through monitoring of process parameters and non-destructive characterization of the product. The control of quality is through a feed back loop method. Various steps involved in the IPM technology include study of the process flow sheet, understanding the process variables which influence the quality, characterization of the product using nondestructive testing (NDT) techniques to ascertain the relation between quality (property), NDT and process parameters, handling statistical data on quality using advanced concepts like heuristics, fuzzy logic etc. and integrating the information obtained and the knowledge acquired into an expert system for on-line adoption through feed back loop to specific applications. Validation of the theoretical models with the experimental interpretations obtained through smart process and NDT sensors and tying the loose ends towards using this expertise for on-line production activities are also important segments of this technology. From these steps, it can be understood that the IPM technology is highly interdisciplinary in nature needing specialists from materials science, NDT, process technology, instrumentation, data management etc. IPM is a significant move to produce materials fit for the purpose without the need to check the quality after the product is made. Adoption of IPM technology leads to products with zero percent defects. IPM technology demands improvement in the NDE technologies for enhancing the sensitivity for defect detection and complete characterization, development of products with closer tolerances etc. to ensure reliability in their performance. Employing such technologies and strategies makes it possible to withstand the impact of global competition and economic liberalisation.

As part of the DST programme on IPM, a set of activities was initiated with different organisations for the development of suitable methodologies for weld related applications and for ceramic insulators. Acoustic emission (AE) and thermography data for a large number of welds were collected and analysed for end cap, spacer pad and bearing pad welds related to critical nuclear fuel subassemblies and calandria tube welds used in pressurised heavy water reactor, in collaboration with Nuclear Fuel Complex (NFC), Hyderabad. Acoustic emission and thermography techniques for monitoring narrow gap welds at Welding Research Institute (WRI), Trichy have been established. The theoretical and experimental suitability of detection of defects in ceramic insulators and blanks have been established for both conventional and real time radiography. This work has been done in collaboration with W. S. Industries, Chennai. In collaboration with M/s. Raman Boards, Mysore and Indian Institute of Science, Bangalore, eddy current and radiographic techniques have been developed for on-line detection of metal particles in insulator boards used in transformers. A fuzzy logic based estimator has been developed for resistance spot welding, in collaboration with Indian Institute of Technology (IIT) Madras, Chennai. Ultrasonic parameters have been identified for detection of presence of hard intermetallic precipitates in beta quenched zircaloy-2 material.

In the case of end cap welding, on-line AE monitoring during welding was carried out on a number of elements without fuel pellets and with fuel pellets. Imperfections such as end squareness and ovality of tubes, graphite impurities etc. were introduced and the AE data was acquired during welding. Thermal imaging was also carried out on these elements after the welding process was completed. Analysis of the AE data has indicated that it is possible to detect formation of defects during welding process due to different imperfections, as the AE signals generated in the case of defective welds are stronger and various AE parameters like, counts, energy, peak amplitude, rise time and event duration are distinctly different for the good and defective welds. Analysis of the cooling patterns and evaluation of the rate of cooling from thermal images have indicated that it is possible to reliably detect the imperfections such as graphite impurities and sparking during the welding process. A comparison of the thermal imaging data with the results obtained from the subsequent ultrasonic testing and metallography studies has confirmed these predictions.

AE monitoring was also carried out during spacer pad welding and bearing pad welding of the fuel elements. The data generated was subjected to pattern recognition and cluster analysis. Two distinct clusters can be identified between defective welds made with low pressure and one coin removed and good welds. These studies demonstrated the potential of advanced techniques and methodologies for obtaining quality products with high reliability.

One of the intermediate product for manufacture of ceramic insulators is the green compact. It is possible that cracks and voids may get introduced in to the green compact and these may act as sites for initiation of breakage of the insulators during firing stage. Detection of such defects in green compacts and rejecting them would minimise such breakages in firing stage, thus enhancing the cost effective productivity. A few ceramic compacts with simulated defects have been tested with film radiography and real time radiography. Radiography based techniques demonstrated a sensitivity of about 2% for detection of defects with reliability. This is in agreement with the theoretical estimation for detection sensitivity made for these insulator material with appropriate radiographic parameters. The real time radiography based procedure together with image enhancement methodologies has been developed for evaluation of these green compacts which can be implemented on shop floor. The successful venture has encouraged the further continuance of the project with newer objectives such as development of an intelligent welding process for welding of austenitic stainless steels, development of intelligent extrusion and forging processes, on-line quality monitoring and control of bullet casings, etc.

NDE in Cultural Heritage

India has a rich ancient cultural heritage which has left its evidence in the form of idols, icons, paintings, rock carvings, monuments etc. NDE plays a significant role in conservation, restoration, authentication (finger printing) etc. For example, systematic studies are made extensively for finger printing of South Indian Bronzes for authentication, for understanding the metallurgical technology adopted for producing these marvelous art objects. The Department of Science and Technology, the Archaeological Survey of India and the Department of Culture have taken great interest and initiative and are providing total support for these projects, in order to preserve and conserve these precious objects.

Training and Certification In NDT Techniques

Training and certification of personnel is one of the most important and crucial areas that has attracted world wide attraction. It is well recognised that the key to the success of any operation is the availability of qualified personnel. NDT is no exception. In fact, since most of the tests in NDT rely on human interpretation, reliability of NDE test results strongly depends on the quality of the trained personnel. Proper and adequate training of NDT personnel is therefore a must to ensure that the capabilities of the techniques are fully exploited and correct interpretation and hence evaluations are made since they have a significant bearing on the quality and reliability of components /systems. Certification schemes are also vital to achieve desired and uniform levels of competence and standard of work throughout the country. Thus, a system or methodology has to be evolved and implemented to objectively evaluate and certify the competence level of NDT personnel. Those who were working in the field of NDT even in the 50's and the 60's realized the importance and essentiality of training for NDT personnel. Familiarisation talks and lectures on NDT were arranged in different organizations and at various places. With the formation of a Professional Body on NDT (Indian Society of NDT, ISNT) in 1972, the training programs were pursued in a systematic manner. Participants from various industries and organizations were invited and structured courses on specific NDT methods were conducted with practical demonstration.

With the rapid increase in the adoption of several NDT methods and techniques in several industries and also due to the greater insistence on Quality by the customers, the need for recognition and harmonization of training and certification of NDT personnel was being felt by the industry and regulatory bodies. With this in view, the Bureau of Indian standards (BIS) was requested in late 80's to take up the task of formulating an Indian Standard on this subject and in line with prevailing international standards. BIS rightly recognized the need and importance of ensuring the quality of trained and certified personnel and took up the issue in its MTD Sectional Committee (SMDC 21). ISNT took an active part in the deliberations and finally the Standard IS-13805 was printed and released in 1993.

Meanwhile ISNT was recognized as National Sponsoring Organisation and India as accredited Examination Centre by the American Society for Nondestructive Testing (ASNT) for conducting ASNT-Level-III Examination. Starting from 1986, so far eleven examinations have been conducted till last year in India and about 400 persons mostly from India have benefited by this interaction and got ASNT Level III certification. While formulating the Indian standard on Training and certification of NDT personnel along with BIS, ISNT in parallel constituted the National Certification Committee in early 90's to start work on various procedures necessary to meet the requirements proposed in the draft standard. Later when the standard IS 13805 was released, the certification committee was renamed and broadened as National Certification Board (NCB) in 1997. Keeping in view the objectives of NCB as stipulated in IS 13805 and its vital role and importance in setting a high standard in all related activities of Training and Certification, the membership of NCB was carefully drawn from various public and private sector organizations, third party inspection agencies, regulatory bodies, professional bodies and research and educational institutions. Some of the major responsibilities of NCB as outlined in IS 13805, include:

1. Initiating, maintaining and promoting the national certification scheme as per IS 13805
2. Administering the procedures and operation for certification in accordance with the standard
3. Prescribing a code of ethics which shall apply to certificate holders
4. Accredit training agencies in NDT methods
5. Keep all appropriate records and issue the certificates and other written testimonies
6. Interact with recognised international bodies for mutual recognition of certification and international harmonisation.

Right from its inception, till date, that is within a short span of about three years, NCB has many achievements to its credit. The most significant ones include:

a. Finalisation of guidelines and procedures for conducting ISNT Level I, II and III examinations.
b. Evolving the responsibilities of the Chapters, Zonal board, Examiners etc. in conducting Level I, II and III examinations
c. Evolving and finalising the procedures for revalidation and re-certification
d. Ensuring harmonisation in the formats of certificates, forms, course notes etc.
e. Procurement/collection of Test specimens with calibrated artificial/natural discontinuities for practical training as well as for examination purposes. These are being loaned to the chapters for use during certification programs.
f. Identification of suitably certified and experienced personnel from different regions/chapters for conducting examinations.
g. Developing criteria for accreditation of NDT training centers and examination centers in different regions.
h. Development of database of certified personnel.
i. Preparation of a Quality Manual for NCB activities so as to enhance our efforts for recognition of NCB by government and other international organisations.

The quality manual outlines the quality policy and quality objectives of NCB.

NCB has also initiated measures to get recognitions from Central Govt. bodies such as the Department of Science and Technology, Ministries of Education, Human Resource Development, Industries etc. for the Level I, II & III certificates issued by ISNT. It is also actively interacting with the Bureau of Indian Standards in its endeavor to update the technical contents in tune with the latest developments and requirements of the industry. It has also strived to introduce additional techniques such as infrared thermography, visual testing and acoustic emission in IS 13805. Till the advent of international harmonisation, to cater to the needs of the candidates requiring certification of international bodies, NCB also conducts ASNT level III certification once in a year with the active support of ASNT. ISNT has so far qualified about 3500 persons in Level I, 7000 persons in Level II and 500 persons in Level III. To our knowledge, India ranks the 5th country in the world in terms of the total trained manpower in NDT. The international scenario on the aspects of training and certification aspects is discussed below:

One of the oldest and most widely acclaimed training and certification scheme is that of ASNT. Started in 1977, the ASNT Level III certification program and SNT-TC-1A has a track record of professionalism and excellence in NDT personnel qualification and certification. These programs are accepted throughout the industry across the USA and most parts of the world. There are over 3700 Level III personnel world wide. Realising that industry has varying needs for personnel qualification and certification ASNT has now adopted a three-tier approach. SNT-TC-1A continues to be available for those desiring tailored, employer-based programs; CP-189 provides the minimum standard requirements while the new American Central Certification program (ACCP) with its emphasis on hands on practical training will offer independent examination and certification for mutual national and international acceptance.

In the European region, each country has its own training programs (like the British have PCN, French COFREND etc.). However, after the unification, international recognition is being achieved in Europe through the ECNDT multilateral recognition agreement whereby all the ECNDT countries are preparing the framework to recognise the certification of other countries if they comply with EN 45013 and EN 473 and certain other clauses. Countries such as Canada and Japan are also taking up the task for accreditation of their bodies by ECNDT and other major industrialised countries.

Every developed and developing country has its own training and certification program. While some such programs (such as ASNT, PCN, etc.) are well structured and established, many are in the nascent stage. However, a unanimous opinion that has been expressed by the developed and developing nations is the need for world harmonisation and international recognition of NDT personnel. All the international members supported the idea of a common framework of certification categories based on a common core and a menu, of options. It was agreed upon by all present that ISO 9712 must be the basis for harmonisation. Once a NDT society commits to ISO 9712 and accredited through the known methodology, it should be able to have the support of other NDT societies when they seek recognition. The ultimate goal is the formation of an International Accreditation Forum which would accredit the national body once it complies with all the requirements.

The main mission of Training and Certification programs, of any national or international body is to provide a measure of NDT personnel competency that is reliable, valid, and cost-effective. With the rapid advances in the field of engineering, technology and material science, the science and technology of nondestructive testing and evaluation is also expanding with newer and better methods/techniques. It is therefore needless to emphasize that training and certification activity would require continuous improvement and upgradation commensurate with industrial, national and global needs and should also keep pace with the state-of-the-art technology of NDT & NDE. The mission of NCB is to provide training, standards, and services for qualification and certification of NDT personnel in tune with the national and international needs.

A Perspective On NDE: Recognition Of Pushers, Pullers & Gaps In The Indian Context

I intend evaluating the science and technology of NDT&E on the basis of criteria proposed by Alrein Weinberg, who, while assessing the value of science, asserts:

'There are two criteria for the assessment of the value of science: (i) the underlying value

in the practice of science is truth and what achieves truth efficiently is the most valuable and (ii) the underlying value in the administration of science is utility and what is most useful (in addition to its being true) is the most valuable.'

The discipline of NDT&E satisfies these two criteria fully in relation to research and applications. I do not know of any other field that has achieved such a laudable objective: sound human beings operating sound engineering components and plants. Contribution of NDT&E science and technology towards reliable medical diagnosis, achieving desired quality levels and enhancing productivity of plants by avoiding failures of components are well recognised. It is also appreciated that many technologies related to production of power and chemicals, different modes of transport i.e., road, rail, air, etc. are validated and acceptable to society because of contributions made by NDT&E science and technology. However, contributions of NDT&E science and technology to characterise cheese, meat, corn, tea leaves, rice, toys, art objects and cultural heritage monuments are not well recognised though these are extremely fascinating and challenging.

NDE is practiced in qualitative, quantitative and analytical modes. A qualitative approach to any phenomenon attempts to describe the phenomena/results with little or no measurements made to substantiate its arguments. With this view in mind, we can say that early approaches to NDE were largely qualitative. For qualitative NDE, acceptance standards are available and the expected technology level from this approach is generally achievable. It uses appropriate sensors and first order instrumentation just enough to describe the phenomenon under observation. This sort of an approach, unfortunately, is still practiced in many industries.

A quantitative approach not only describes a phenomenon precisely, but also substantiates this description numerically, with the help of measurements and correlations in the form of equivalent graphs, tables, etc. It removes subjectivity from interpretation and guarantees the same measurement values and interpretation, no matter who experiments. Standards are being evolved for a quantitative approach. This is being increasingly used in the industry. A few typical examples are classification, size and shape distribution of defects, microstructure description etc. with measurable physical quantities. Such an approach requires appropriate sensors, advanced instrumentation and signal processing and analysis. With the advances in sensors, electronics, instrumentation and computer technology, more and more conventional NDE techniques are being exploited in a quantitative manner. Examples are C-scan, P-scan, acoustic microscopy, x-radiography, laser interferometry, etc. The distinguishing aspect of quantitative NDT&E is the measurement of a physical phenomena and its correlation with an observable state in the sample / component.

We say that a scientific methodology is analytical, when the methodology is firmly footed on a mathematical basis and is able to both explain and predict the expected results with defined precision. A few NDE techniques, like tomography, synthetic aperture focussing technique, grain size estimation using ultrasonic measurements, have attained this status.

Though quantitative and analytical NDE terminology are interchangeably used, quantitative NDE to qualify for analytical status, must meet the additional criterion of predictability of results / numbers, on the basis of a tested model. The keyword in qualitative approach is 'description'; that in quantitative approach is 'measurements'; and in the case of analytical approach these are 'modeling' and 'predictability'.

The spectrum of NDT&E techniques can be classified into these three levels, the levels themselves being in a state of dynamic evolution towards betterment. The current NDT&E scenario has matured from just being a qualitative science and technology to a quantitative plane, and is ever striving to completely transform some of its components into an analytical science and technology.

Internationally NDT&E is full of intelligent solutions and avoidable disappointments. Successes are reported in literature with a sense of pride, but disappointments remain with the individuals and teams. Lack of awareness and capabilities to comprehend the complex engineering problems many a times results in inappropriate and inadequate methods. The space shuttle challenger accident, the Bhopal gas tragedy, the insulation failure in the Swiss aircraft over Newfoundland, and our recent train accidents are but some of the examples that highlight this inadequacy. All these failures, on the hindsight, bring to the focus an important aspect that without any new technology, these failures could have been avoided. It also emerges very vividly and clearly that these accidents are the result of improper quality management systems in the organisations involved.

It is my conviction that rather than a mere statement, a holistic approach, integrating materials science with engineering performance should be presented, gluing the two ends of spectrum using effective quality management systems. Precisely, this integration is what is lacking today. It is also true that these lessons have not percolated down even to high risk, high technology industries, leave aside the manufacturing and infrastructure industries. A question then arises as to what should be done to change the situation in an effective and expeditious manner. Another limitation is the lack of adequate emphasis on quantitative measurements in NDE science and technology.

After a detailed consideration based on my research and application experiences over the last three decades, various Pullers, Pushers and Gaps in the field of NDE science and technology are identified in the Indian context. The pullers are the vast resources in the form of multi disciplinary facilities, expertise and experience which are available to meet the targets. The pushers are the updated targets or demands set by the user community for enhancing the quality of product and service. The gaps are the differences between the present status of NDE and the enhanced demands of the user community which act as driving force for systematic R&D efforts to bridge these gaps.

As part of the analysis carried out on the pullers, pushers and gaps in the NDE, the vision for the future and suitable directions have been identified for the growth of NDE Science and Technology in India. For this, the following factors have also been taken into consideration: (1) The immense potential available in India, (2) The gains of ever expanding collaborative programmes between Indian and international institutes like Fraunhofer Institute for NDT (IZFP), Saarbruecken, Germany, Federal Institute of Materials Research (BAM), Berlin, Germany, National NDE Centre, Iowa State University, USA, World Federation of NDE Centres, USA, Moscow Scientific Industrial Research (MSIA) 'SPECTRUM', Moscow, Russia, Moscow Power Engineering Institute, Moscow, Russia, Institute of Metal Physics, Ekaterinburg, Russia, International Committee on NDT (ICNDT) etc., (3) The challenges ahead based on the projected demands from industry for quality under global competitive atmosphere etc.

The Pullers or Available Resources

- Knowledge-Bases in Interaction of Probing Medium and the Material / Component being Tested
- Development of Generic Knowledge-Based Decision Support Systems
- Expertise in Forward and Inverse Problems

- Interactions with National and International Forums
- Improved Structure-Defect-Property Correlations
- Codes and Standards
- New Techniques
- Multi-Disciplinary Pursuit
- Computers
- Instruments
- Sensors
- Robotics and Automated Inspection
- Signal and Image Processing and Analysis; Pattern Recognition
- Data Fusion of Complementary Techniques
- NDE Series of Seminars; World, European and Asia-Pacific
- International Collaborations; Workshops on Specific Issues;
- Training, Certification and Harmonisation
- Changing Mindsets of R&D Groups and Industry
- Support from Regulatory and Government Organisations
- Strides in Basic Research

As we have seen earlier, the Pushers are the challenges, targets, goals and action plans of an organisation, decided by the management based on the assessment of the current technology and vision of the organisation. These are identified as follows:

The Pushers or Targets

- Competitiveness on the Basis of Quality, Cost and Delivery
- Challenging Projects in Strategic Sectors
- Sanctions Regime
- Mega Projects in Public and Private Sectors
- Desire to exploit New Science and Technology
- Risk-based Management for Applications
- Emphasis on Concurrent Engineering, for Reducing the Time of Completion of Projects
- Characterisation of New Materials
- Reduction of Scrap and Emphasis on Recycling
- Stretching Performance Limits; Opportunities to Extend the Life of Assets
- Ageing Plants and Infrastructure; Life · Prediction and Residual Life Assessment
- Integrated Lifetime-Cost as a Criteria for Taking Decisions
- Changing Quality Paradigms B Robust Processes, 6 sigma quality, TQM and Total Productivity Management (TPM)
- Intelligent Processing
- Reverse Engineering
- Micro Engineering and Mechatronics
- Cultural Heritage
- Spirit of Innovation

A Perspective on TQM in the Context of NDT&E

From a global perspective, we can readily see that the Pushers mentioned above are the various manifestations of the well-known industrial mantra, viz., Total Quality Management (TQM), Total Productivity Management (TPM), etc. on a cost effective and innovative basis. We need to address the concerns of TQM, understand its genesis and basic components, in order to exploit the available resources. Total Quality Management represents a comprehensive procedure, methodology and approach towards quality assurance and management, that transcends the barriers of materials, processes, countries, time and space, in order to satisfy the customer right from the introduction of any product or service in the market, through its evolution and use, till the complete phasing out of that product or service, only to be replaced by a better one. The administrative and scientific targets mentioned above as Pushers are the cogs and wheels of the TQM.

Total Quality Management is a topic discussed often in view of its importance to excel in global competitiveness, achieve brand status and reap large profits. TQM has often been explained in qualitative terms. Thus, it is essential to consider a valid question, i.e., what is TQM? Is it the highest destination in the ladder with steps of quality control, quality assurance, quality audit, ISO 9000, quality improvement and TQM? Does it relate to the character of the company, vision of the leader, an ideal (rarely realisable), guaranteed profits through customer delight, brand status, commitment of the employees and the employer to a common focus, policy of the company through *quality circles & quality improvement* etc.? In a way, TQM is the sum total of all these small, yet important aspects. Strict control, documentation and updating of data in the following areas are mandatory for TQM: [1] Choice of raw materials, [2] Processes, [3] Final product, [4] Marketing, [5] Services (with respect to both spatial efficiency and temporal efficiency), [6] Product support; customer support, [7] Product upgradation, [8] Education to the customer about the product or the service, [9] Gradual phasing-out of any product and its related services, [10] Gradual introduction of the new product, [11] The beginning of the next equivalent cycle leading to a better product or service.

NDT&E and TQM - Where Pushers and Pullers Meet

Each of these stages of TQM, in any product or service, can be strictly monitored using NDT&E. Two aspects assume importance here, regarding the use and role of NDT&E in achieving TQM. Firstly, the term Nondestructive Testing is used here, not merely as an assembly of well established conventional NDT&E techniques, but as a complete embodiment of interdisciplinary areas, right from Physics on the one side to Computer Science on the other, working together as Pullers to bring out a distinct synergistic advantage. Secondly, the role of NDT&E as envisaged in any TQM program is one that focuses on prevention rather than cure. Doing things the right way even if it is done for the first time and repeating this every time is the fundamental aspect of TQM. In other words, the concept of zero-defect (100% Quality Assurance) should be accorded prime importance. Testing and inspection of products and services as they evolve have assumed greater importance, rather than the NDT&E of finished products. In the final phases of the evolution of TQM, NDT&E of finished products may also become a thing of the past. Similarly, Acceptable Quality Level (AQL) is a concept that is totally opposed to TQM, and is often preached by companies that cannot get their act together to achieve TQM. An AQL is subjective and more often sets up a dual standard. AQL is also contradictory to the accepted norm of continuous improvement. TQM requires 100% reliability in the products, services and commitment of the people of the organisation that strives to obtain TQM.

Having studied both pullers and pushers in perspective, we now turn to a practical perspective, by identifying the gaps in NDE Science and Technology.

The Gaps or Required Resources and Strategies

- Non-availability of Knowledge-bases with Industries; Especially Medium and Small-sized, regarding Indigenous Capabilities
- Uncertain and Limited Interaction with Decision-Making International Forums such as International Standards Organisation, International Committee on NDT, etc.
- Mechanism and Time Taken for Comprehensive Response from R&D Groups to Industry and Vice-Versa
- The R&D and Industry Mindset; Bureaucratic Blockages in S&T Knowledge Flow to

Industry
- Emphasis on Imported Technologies and Lack of National Expertise in Critical Areas
- Lack of Long-term Perceptions and Priorities
- A Few Strong Groups; Large Demand; Slow Dissemination and Absorption of Knowledge
- No Services at the High-end of Technology in Private Sectors
- Slow Machinery for Establishing and Adapting Standards
- Sub-critical Academic Activity; No NDE Centres; Inadequate Human Resources Development
- Lack of Indigenous and Specialised Equipments & Consumables
- Lack of All-pervading Quality Culture and Quality Management Systems
- Inadequate Sustained Interaction Between Basic Materials Sciences and Applied NDE

A detailed look at the Pushers would reveal that these are statements of intent, which would act as avenues for prosperity in the next millennium. In a market economy, towards which all developing countries are moving at a rapid pace, these are the benchmark targets. The established goal of these pursuits is Total Quality Management. These are essential challenges to be met by any developing economy to make it a globally competitive nation with good standards of life for her citizens.

The required resources and strategies identify some of the gaps that need to be bridged. The very existence of gaps is a reminder of the work ahead of us in meeting the challenges through:

- o building effective two-way bridges between the R&D and Industrial units
- o taking a pro-active role in decision making forums at international levels
- o building expertise in nationally important technologies
- o integrating the fruits of basic sciences research into industrial products and applications

As a comprehensive and synergistic approach to overcome the gaps keeping in mind the Indian scenario, where there is technical expertise available in almost all conceivable areas but appear to have remained concentrated in certain pockets both in terms of sectors as well as geographical locations, it has now been proposed to start three National NDT Centres tentatively at Calcutta, Jamshedpur and Chennai in collaboration with the local academic or R & D institutes. It is envisaged that these Centres of excellence would act as hubs for providing NDE related education, training and consultancy to the required institutes/ industry through. a set of identified experts drawn form a spectrum of professions.

Future Directions

The conventional approach tends to advocate a single technique at a time, for achieving a single or a few objectives. Results from the application of the first technique are normally used for planning subsequent tests (also applied sequentially). However, in most cases, results from the previous campaigns are not fully utilized in planning `the subsequent campaigns. The volume of data collected during each inspection campaign is quite high and correlating the results and making effective decisions become tedious. Moreover, many a time, different inspection personnel will be carrying out the condition assessments, at different stages of the life of the plant. However, carrying out the inspection with identical or comparable sensitivity and reliability and proper utilization and interpretation of data and results from previous campaigns are essential for the success of the inspection objectives. Constraints on time for carrying out the assessments add another source of possible errors. In order to carry out effective and reliable condition monitoring, it is thus necessary to utilize a number of modern approaches including, tandem application of techniques, data fusion, improved storage, management and presentation of data, and use of automation in inspection.

Multi sensor data fusion and integration can be defined as the synergistic use of supplementary and complementary information from multiple sources to assist in the accomplishment of a task. During NDT&E, these sources of information can originate from multiple identical sensors such as two (or more) eddy current sensors or from multiple different sensors such as one eddy current and one ultrasonic sensor. In the simple case of two (or more) identical sensors, one sensor can be used for decision making and the other for consultation, to compare or check information conveyed by the first one. The final decision can be made from combination of information from one or both sensors into a single feature.

Computer Aided Visualization (CAV) could be seen as an input to the human neural system (brain), and helps in improved interpretation. CAV in the form of animation and simulation can help in increasing the efficiency of the interpreting expert and of the reliability of testing in many ways. It also helps in planning effective NDT&E on a component, and as an aid to find the location, orientation and sizing of the defects present in the component. Planning of NDT&E with a CAV system enables the operator to be presented with a variety of options for simulating the injection of the probing wave, viewing the response, selecting the probing method, optimizing the scan path and direction, etc. This technique, when employed for a critical component of a structure, its vibration levels can be visualized.

One of the emerging possibilities to effectively utilize the data and knowledge explosion is to explore the concepts of artificial intelligence (AI) wherever applicable. Successful implementation of AI concepts, in the form of verified and validated expert systems (ES) and knowledge-based inference machines are currently being developed for various specific problems. The DESKPACK software, developed in collaboration between the Indira Gandhi Center for Atomic Research, Kalpakkam and the Fraunhofer Institute for Nondestructive Testing, Saarbruecken, Germany, is a decision support system framework developed in Visual Prolog for Windows NT class systems. It consists of modules for signal and image analysis and processing, knowledge representation and uncertainty handling through fuzzy reasoning.

Today one sees a sea change in the medical field with respect to international networking or expertise for both diagnostic and treatment activities, thanks to satellite communications. It is now possible to provide on-line evaluation of the diagnostic reports and guidance for treatment methodologies including carrying out of surgeries under remote supervision of international experts. The day is not far off when similar approaches are adopted for assessment of performance and life extension of components. All the data from plants can be transmitted via Wide Area Network and satellites to institutes with expertise and experience who would analyse and recommend appropriate measures for reliable and safe performance of industrial components on a day to day basis.

Apart from the various capabilities of nondestructive testing namely, material characterization and high sensitive defect detection and characterization, the most important from safety and life extension considerations is reliability, i.e., the ability to detect a given flaw reproducibly and with high assurance in any particular inspection situation and more importantly, the biggest flaw that may go undetected. One can begin by discussing just what one means by inspection reliability. One typically hears the need for inspection reliability stated in an operational sense as the need to find all flaw sizes greater than some critical size, essentially all the time. When one tries to quantify this, it usually involves critical flaw sizes and requires probability of detection/ confidence limit (POD/ CL) mixes. We find that there are various parameters that impact NDT&E reliability- size of defect to be detected, choice of accept- reject criteria, inspection technique used, inspection environment, quality of inspection equipment and of course the very important parameters in the use of a human operator.

In the Indian context, reliability studies have been implemented during inspection campaigns for very critical components such as the rocket motor casing for the launch vehicles where three independent teams were called upon to carry out the ultrasonic evaluation before taking a decision. Similarly in the context of the Prototype Fast Breeder Reactor (PFBR) project, it has been envisaged that those components which would not undergo in-service inspection shall undergo pre-service inspection by two independent agencies using two different techniques for greater reliability.

Until 20 years ago, there was little quantitative information on the effectiveness of NDT techniques especially when they were applied to critical components. This information is vital for the assessment of the integrity of such plants and thus the concept of Round Robin Tests (RRT) assumed importance. The concept of RRT can be better explained through an example of the cooperative International program that became known as PISC, the Program for Inspection of Steel Components. The aim of PISC was to generate the quantitative information on the effectiveness of NDT techniques for a specific problem. As a result of PISC and other exercises conducted, the concept of NDT&E performance demonstration was developed which tends to replace prescriptive standards by performance standards, in view of an effective setting of performance of the NDE techniques in their application. These performance standards demand stringent specifications arising out of performance requirements in demanding environments. An example in the Indian context is the validation of inspection procedures at the different workshops of the Indian Railways spread throughout the country especially for the inspection of the thermit weld of the rails.

During the past several years, a number of design- centered 'global' approaches have been offered that deal both with material synthesis and the manufacture of materials into finished products. Although the structure and constituent components of these approaches differ because of their different end purposes, they share major dependencies on design, theoretical modeling, extensive computations and confirming measurements using various NDT&E techniques. Materials- by- Design (MBD) is an example of these approaches that is focused on the synthesis of materials. A principle purpose of MBD is to produce materials with prescribed macroscopic properties by designing and controlling the microstructure. At the other end of the spectrum, Unified Life Cycle Engineering (ULCE) is an example of a global model for manufacturing. In this case emphasis is placed upon the development of ways to predict the total set of important properties of a product performance, quality, reliability, maintainability and life-cycle costs at the designer's desktop. Taken together, these approaches offer the opportunity for designer controlled materials with specified material properties to be fabricated into components of specified performance, quality, reliability and cost. A logical approach for the development of the NDT&E/ Design link is based upon the Probability Of Detection (POD) concept.

High capital investments and arduously long erection and commissioning time periods have given impetus for the development of remnant life analysis techniques especially with a view to extend the life of the existing units. A variety of techniques have been developed for this purpose and applied to several real life case studies. For example, various methods of remaining creep life assessment are a combination of the following approaches: (1) Methods based on the operational history in which the expended life of a component is calculated on the basis of operational history and material properties and (2) Methods based on in-service examination and/ or testing on the actual component at various stages. The importance of toughness reduction is being recognized recently and is being considered with utmost care in life extension programmes of plant components, particularly those operating at high temperatures and certain corrosive environments. Non-destructive examination on service exposed components allows assessment of the present conditions and structural integrity of the components, but the present day focus is to develop correlations to precisely estimate the remaining life.

In general, no practical nondestructive measurement technique collects enough useful information to allow a totally general and unbiased reconstruction of the flaw by forward modeling approaches. It is thus desirable to have a formalism, which allows these assumptions to be introduced into the data processing in a known and quantifiable manner. This formalism should recognize that the truth of the assumptions is never known absolutely, and can only be assigned a certain probability. A probabilistic inversion technique incorporating these features would have the additional advantage of assigning variances to the estimates of flaw parameters. Such probabilistic outputs would be of particular value when used in conjunction with probabilistic failure models to estimate the probability of failure of a given component.

Conclusions

This paper has discussed the importance of NDE for an emerging economy, India. The current status of NDE science and technology in India has been elaborated. The requirements, strengths and weaknesses of NDE have been identified in the context of Indian scenario and the need to address the gaps is highlighted. It is hoped that this perspective would act as a springboard for bridging these gaps effectively and expeditiously. I sincerely feel that the strengths built over more than five decades are exemplary for many countries, all over the world. A strategy and its effective implementation is considered essential to ensure productivity, safety and reliability of the consumer and engineering products. It is clear that the expertise and experience available in strategic and core sectors would provide the necessary support to food, pharmaceuticals, chemical products and consumer goods industries, where the NDE demands are ever increasing. Formation of national NDE Centres at Chennai, Calcutta and Jamshedpur with the mandate to undertake consultancy and industry sponsored research, the proactive role of Indian Society for NDT in finding solutions to industrial problems etc. are destined to give further impetus to meet the challenges of enhanced quality levels of the Indian industry. Such an approach would enable increased prosperity and better quality of life to the citizens of India. Finally, an appeal to made to International Committee on NDT and like minded organisations such as International Atomic Energy Agency, World Federation of NDT Centres etc. to use their comprehensive expertise, resources and wisdom with conviction and pace to achieve better quality of life for the inhabitants of this planet.

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Bibliography

[1] Baldev Raj, T. Jayakumar and B. P. C. Rao, Non Destructive Testing and Evaluation for Structural Integrity, Special Issue of SADHANA on Integrity of Engineering Components, 20, pp. 5-38 (1995)

[2] Baldev Raj, K. Viswanathan and C. G. Krishnadas Nair, A Report on the Non Destructive Testing and Evaluation in India, Materials Evaluation, 54, pp. 1270-1280 (1996)

[3] P. Rodriguez and Baldev Raj, Development of In-service Inspection Techniques for Nuclear Power Plants in India, Int. J. Pres. Ves. and Pip., 73, pp. 59-68 (1997)

[4] Baldev Raj and T. Jayakumar, NDE Methodologies for Characterisation of Defects, Stresses and Microstructures in Pressure Vessels and Pipes, Int. J. Pres. Ves. and Pip., 73, pp. 133-146 (1997)

[5] Baldev Raj, M. T. Shyamsunder and S. Ranganathan (eds.), Proceedings of Workshop on 'NDE Science and Technology for Quality Improvement', INAE-ISNT-QUNEST, Bangalore, Oct. 1999