ICNDT
The World Organisation for NDT

The 2015 ICNDT Guide on

Research and Development in NDT

Non-destructive testing:

why it is important and why more research and development should be supported

July 2015

ICNDT

The World Organisation for NDT

Non-destructive testing:

why it is important and why more research and development should be supported

Acknowledgements: http://bit.ly/1GEilcR
http://bit.ly/18A04yn

Contents

Section 1

Introduction

NDT and diagnostic technologies such as condition monitoring play a crucial role in assuring the safety of modern societies. Major uses of NDT include transport (for example planes, trains and ships), energy infrastructures (oil & gas rigs and pipelines, power stations) and manufacturing (steelmaking to electronics). However there are many other applications of NDT that are essential to protect our safety, such as checking the welds on fairground rides or the towers and cables of ski lifts.

The capabilities of NDT have improved substantially in recent years and are steadily improving thanks to successful research and development, but even more challenging requirements continue to arise.

More research and development is required to:

- reduce the limitations of current application;
- develop new applications not previously thought possible;
- develop techniques for new materials and processes.

NDT uses many different physical principles to detect flaws and it is necessary to understand the physical principles as well as the capabilities and limitations of each technique and to check that reliable results can be achieved in the real life application. This requires attention to all stages of the NDT quality chain, from basic research, technology development and validation through to education, training and procedures. Because of the timescales required to research and develop new techniques, it is important to anticipate future requirements and establish secure long-term programmes.

During the 11th ECNDT 2014 conference in Prague, ICNDT organised a Workshop to consider the importance of NDT, to identify critical research needs and to explore ways of supporting such research. The presentations on which this brochure is based are available on the ICNDT website at: http://bit.ly/1y55N5Y

This brochure highlights why NDT, including diagnostic technologies, is so important; it gives examples of current research and suggests how better funding arrangements for the medium to long term may be encouraged. Industrial users of NDT, as well as universities and other research institutes, have a key role to play, whilst national and international NDT societies can provide the forums for discussion and advice that are so important.

[Footnote]
NDT or NDE?
The acronyms NDT (non-destructive testing) and NDE (non-destructive examination or evaluation) are considered to have the same meaning and are used interchangeably in this document.

Section 2

The importance of NDT and the need for new techniques and capabilities

The global NDT industry had an estimated turnover in 2012 of $5.6bn including products and services (Box 2 and Ref. 1). The most important driver for NDT is maintaining the safety of critical infrastructure, and NDT has maintained growth exceeding 3% per annum in spite of the difficult economic conditions. The largest markets are in energy extraction (for example oil & gas), transport, power generation and aerospace. Significant new markets are also emerging, such as renewable energy.

NDT in manufacture

For critical items such as nuclear power plant, aircraft or satellites, NDT is used at many stages of manufacture to ensure the finished product is fit for service. The inspection techniques must have the right capability to detect and identify the defects that might occur. The design should take this into account, as well as the material properties and duty cycle, to achieve a high value, reliable component.

NDT during service life

Industrial plant and equipment are likely to deteriorate during service life, for example as a result of corrosion or some form of cracking. NDT is often the best way to confirm whether the component is still fit for service. A good example is given in Box 1, which shows how an effective NDT inspection regime has contributed to a major reduction in broken rails on the UK rail network. Improvements in NDT detection capability may allow the intervals between in-service inspections to be extended and hence allow costly plant to operate more economically for longer.

NDT for new materials and processes

NDT is particularly important for new materials and processes. For example, the increased use of composites in the aerospace and motor industries has stimulated new types of X-ray and ultrasonic inspection techniques. The desire for lighter components has also led to new joining techniques (see Figure 1 below), which may require radically new approaches to inspection.

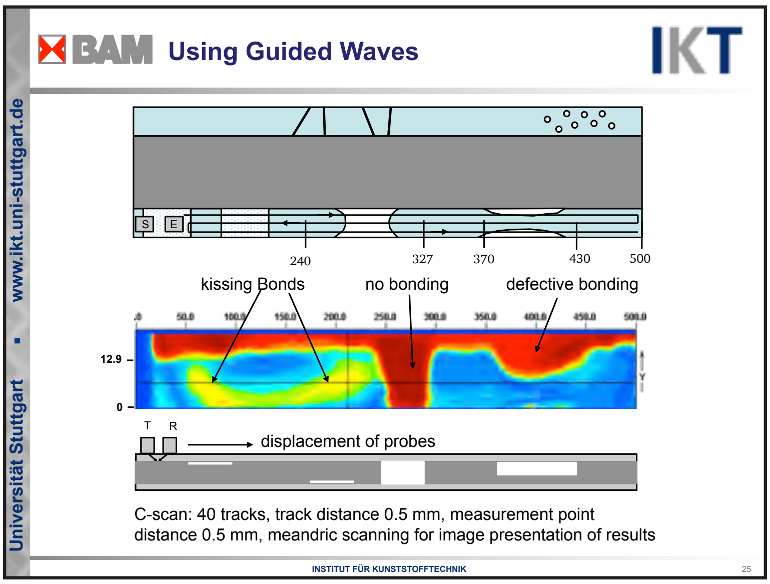


Figure 1. Current research in Germany (BAM and IKT) to use Lamb waves to inspect new types of bonds for lightweight automobile construction.

Box 1: Effective use of NDE leads to better asset management and passenger safety: ultrasonic testing of UK railways

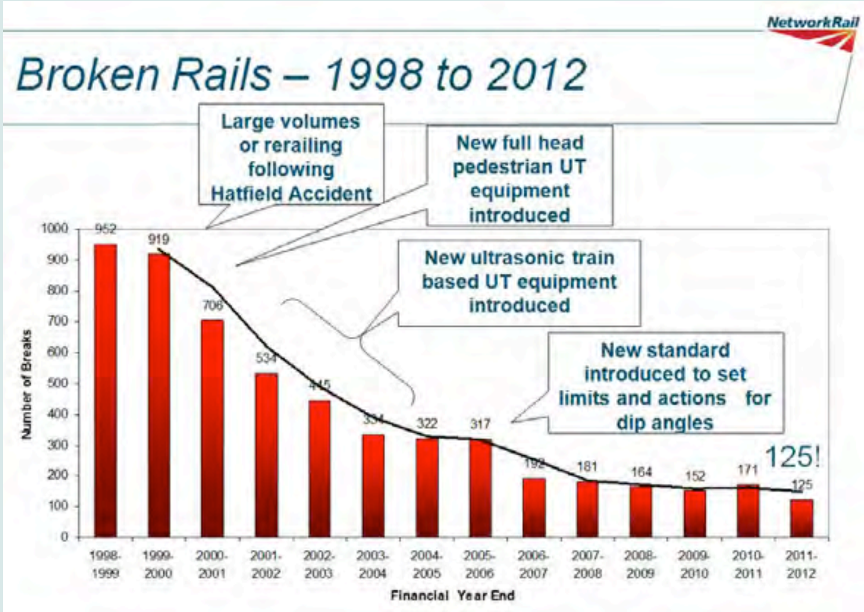


Figure from J.Harris (Ref.2).

The Figure demonstrates the impact of NDT on the UK rail system. Prior to the Hatfield train disaster, rail breaks were running at about 900/year on the network. An improved ultrasonic NDE system enabled faulty rails to be identified and replaced before catastrophic failures occurred. Refinement of the ultrasonic techniques and development of additional NDE methods continues to reduce the rate of broken rail occurrence. Because of these successes, the asset management system has been exported to other national rail networks.

Box 2: UK Landscape report on NDT

The report shows that NDT delivers high impact in terms of safety and maximising asset value for industries such as aerospace, power generation and transport. NDT is crucial for the development of new manufacturing methods and engineering materials, for assuring the integrity of much of the UK infrastructure and for asset life management.

Box 2 continued overleaf

Box 2: continued

This report, compiled by a cross-sector industry-academic working group, identifies the key opportunities and challenges for the UK NDT community. It concludes that making the most of available benefits in the future requires planning now, to deliver research and development and related activities when needed in the future.

The medium-term objectives identified include:

- better quantification of NDT performance and reliability;
- extended capability of NDT, for example, faster, cheaper and more sensitive;
- new NDT methods for emerging designs and materials;
- increased automation and robotic NDT, especially for difficult access;
- improved liaison with other disciplines to optimise design for inspection.

The longer-term strategic objectives include:

- more integration of NDT data with operational conditions and duty cycles;
- far more real-time automated inspection to achieve defect-free manufacture;
- extensive online monitoring and smart structures supported by precision-targeted NDT;
- much reduced use of disruptive in-service NDT by combining high-fidelity manufacturing inspection with structural health monitoring in service.

Section 3

3.1 Some examples of improved NDT becoming possible because of successful research and development

Much of the current research and development may be grouped in four categories:

1. Reduction of the limitations of current applications;
2. Development of new applications not previously thought possible;
3. Development of techniques for new materials and processes;
4. Reduction of the need for NDT by in-service monitoring.

Examples of current work in each category are illustrated overleaf:

3.2 Reducing current limitations, for example sizing capability

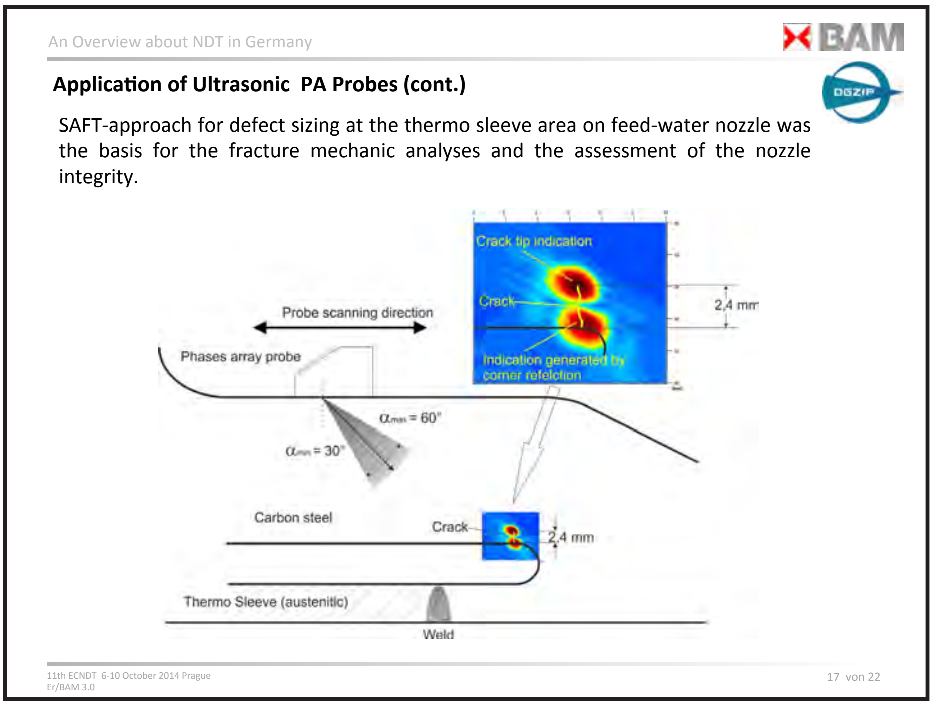


Figure 2. An example of using ultrasonic phased array technology with a synthetic aperture focusing technique (SAFT) to analyse and display the data. This improves on the limited resolution of conventional ultrasonic inspection and improves the ability to identify and measure the critical features of defects. If the crack size is known accurately, it is possible to predict whether a component is safe to continue in service or whether it must be repaired or replaced immediately. (A. Erhard, Ref. 2).

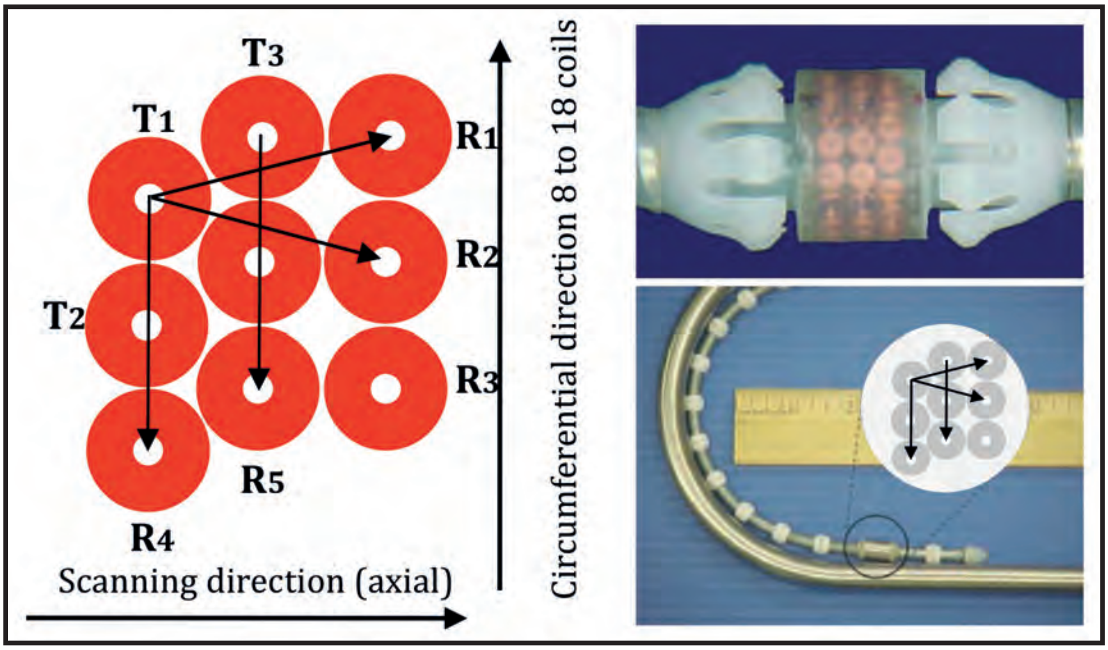


Figure 3. Another example of overcoming existing limitations is the use of multi-transducer eddy current arrays for steam generator tube inspection. Using different combinations of transmit and receive coils facilitates the detection and interpretation of a wider range of potential defects in any of the potential orientations.

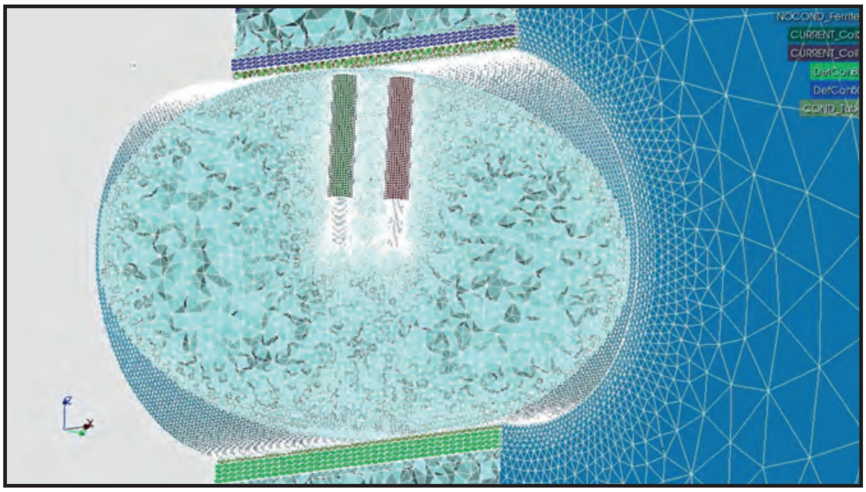


Figure 4. Code Carmel 3D (E. Martin, EDF).

Mathematical modelling of new NDT techniques is important to understand the capabilities and limitations. EDF and CEA in France have pioneered such modelling, which is shown in this example of finite element computation used to perform parametric studies for eddy current inspection of nuclear steam generator tubes.

3.3 New applications not previously thought possible – Portable computer tomography

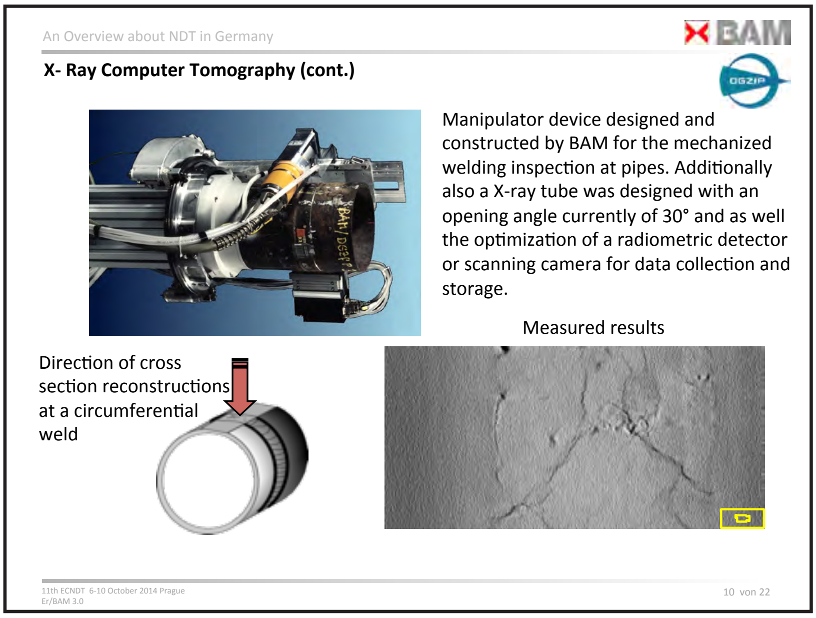


Figure 5. Until comparatively recently, X-ray computer tomography involved large installations which were difficult to transport to site applications with limited access. BAM, Berlin, has developed a miniature device by re-designing the X-ray tube and detector as well as the scanner. High-resolution X-ray images of defects in pipes, including cracks, can now be obtained in confined spaces.

3.4 Inspection of new materials and manufacturing processes

The global market for lightweight materials is estimated to grow at 8.5% per annum from 2014 to 2019, by which time it will have an annual value of $133.1 billion. These materials are used in the automotive, aviation, marine and renewables industries: the highest demand is from the automotive industry (>89% in 2013), followed by the aviation industry (>5%). There is a trend towards hybrid materials using fibre-reinforced composites, light metals (for example aluminium or titanium) or plastics, and such hybrid materials pose particular problems both for joining and for NDE.

The two Figures below show research by BAM, Berlin and IKT, Stuttgart using air-coupled ultrasound to inspect a carbon fibre-reinforced plastic sheet containing impact damage. In spite of the high transmission losses with air-coupled ultrasound, the resultant image has improved resolution and noise level compared to the conventional squirter jet inspection method.

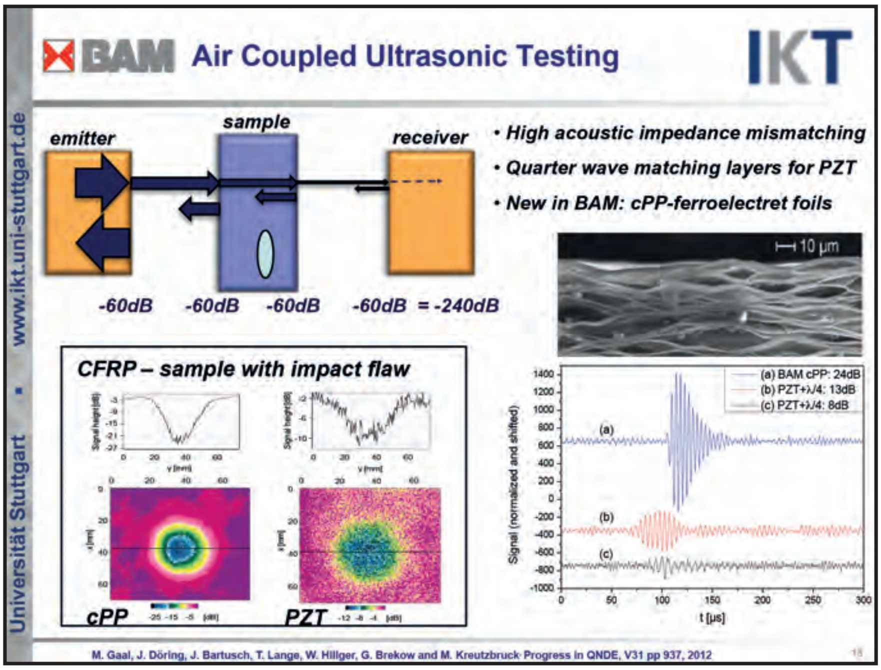


Figure 6. Air-coupled ultrasonics to inspect a carbon fibre-reinforced plastic sheet containing impact damage (courtesy BAM, Berlin).

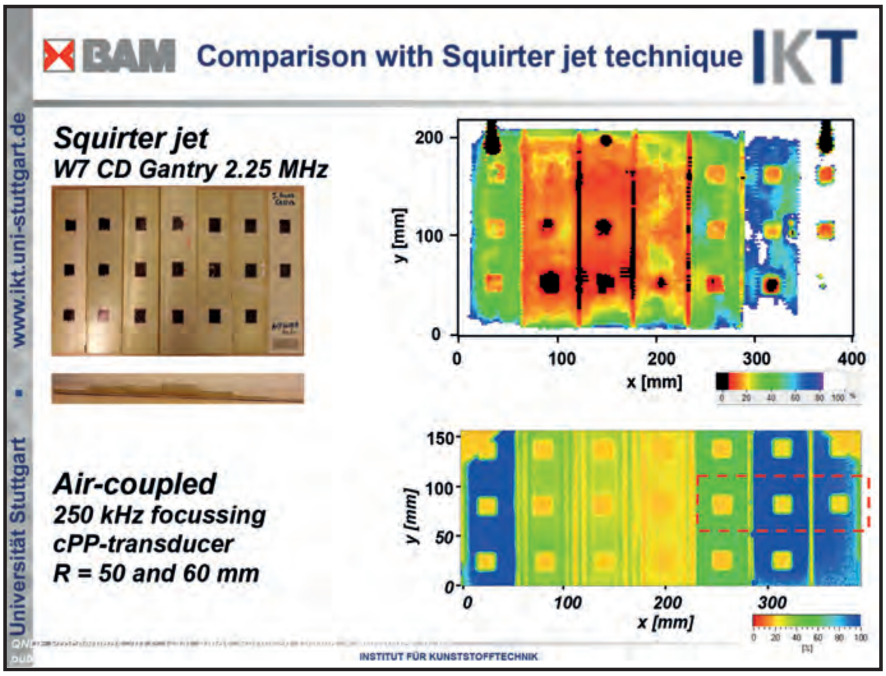


Figure 7. Air-coupled ultrasonics compared to the conventional squirter jet inspection method (courtesy BAM, Berlin).

BAM and IKT are also investigating the use of Lamb waves to check the bonding between layers of hybrid materials (see earlier Box on guided waves).

3.5 On-line monitoring to reduce the need for shutdown and dismantling

Finally, as an example of the types of systems that are being explored for online monitoring of plant in operation, the example in Figure 8 shows how the primary coolant circuit of a pressurised water nuclear reactor might be continuously monitored.

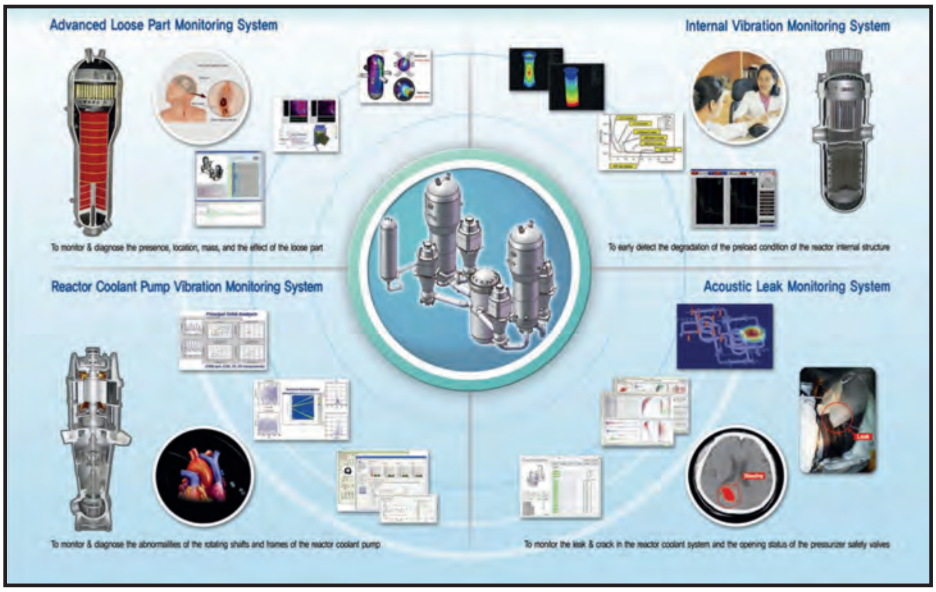


Figure 8. How the primary coolant circuit of a pressurised water nuclear reactor might be continuously monitored (J H Lee, Ref.2).

Section 4

Needs for NDT Research

Whatever the industrial sector, there are a number of common medium-term objectives (Refs 1, 2):

- extending the capabilities so that NDT is more reliable, easier to apply and hence faster and cheaper;
- quantifying more accurately the inspection capability and reliability;
- improving the sensitivity of defect detection;
- reducing the dismantling required for inspections (for example, under insulation or inside engines);
- developing inspection techniques for new materials and processes;
- increasing the use of automation and robotic inspection;
- engaging with other engineering disciplines to optimise design for inspection.

Longer-term objectives include:

- greater application of real-time automated inspection to give defect-free manufacturing;
- greater integration of NDT and operational data so that decisions are based on actual operational conditions;
- use of online monitoring and smart structures supported by high-performance NDT;
- reduction of invasive NDT by high-quality manufacturing NDT and increased use of structural health monitoring (see section on NSSS on-load monitoring).

Figure 9. The Indian Centre for NDE's proposed a list of longer-term research objectives and medium-term development objectives.

In a similar vein, the Indian Centre for NDE has proposed a list of longer-term research objectives and medium-term development objectives as listed in Figure 9.

Section 5

The typical cycle and timescale for developing new NDE technologies

Typical timescales for research, development, validation and implementation of new NDE techniques are illustrated in Figure 10 (prepared by Institut für Kunststofftechnik, University of Stuttgart).

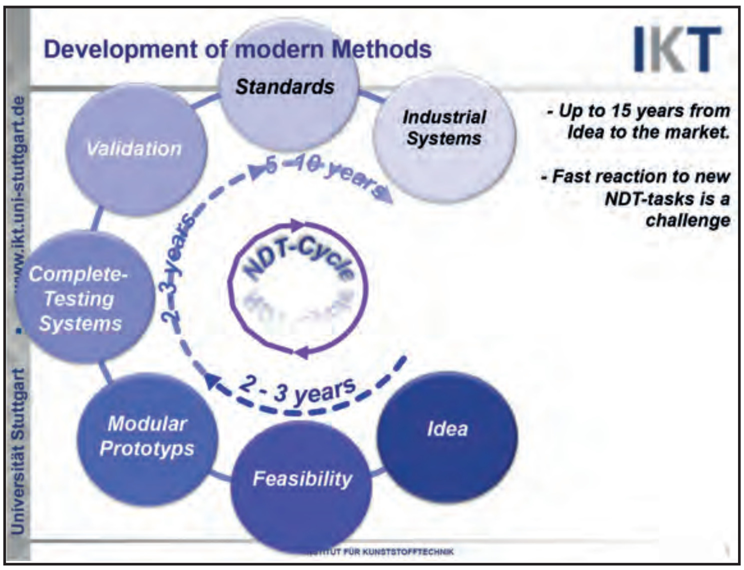


Figure 10. Typical timescales for NDT technique development.

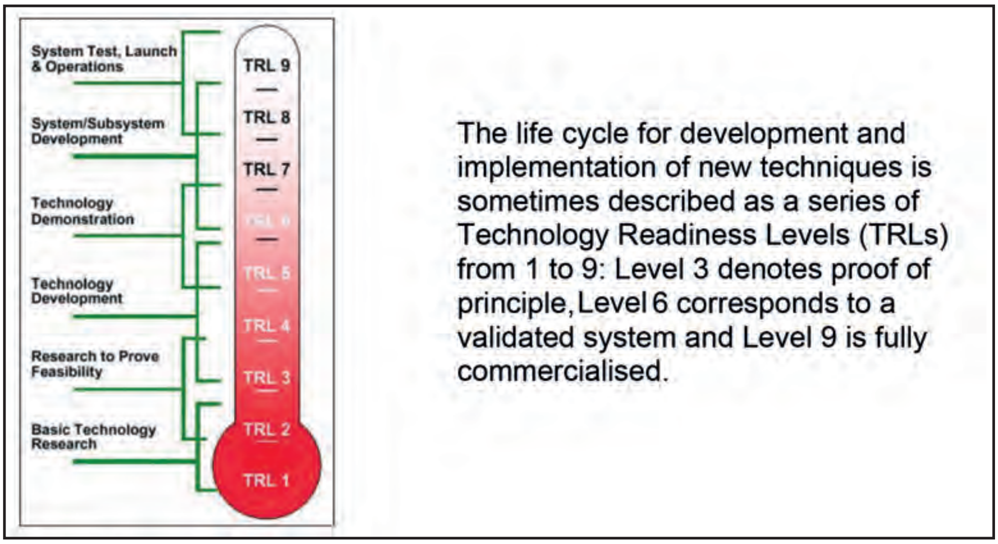


Figure 11. Technology Readiness Levels ('NASA TRL Meter' by NASA).

Development times for new technologies are very substantial (see Box 3 for ultrasonic guided wave systems) and it is essential to start early so that NDT can be developed alongside the development and introduction of new inspections, materials or processes. It is important to anticipate future needs, and it would be unwise to delay starting longer-term research and development until faced with an urgent inspection problem. A better approach is to articulate forward visions of NDT for five, ten or 20-year horizons: industry groups should work with universities on these visions so that they can be the basis of coordinated research, development and implementation programmes. Examples of what may be included in such visions are provided in the UK Landscape report (Ref. 1) and the presentation by the Indian Society for NDT (Ref. 2).

One aspect that deserves more attention is validation; this is crucial because the plant owner – who is financially liable and often legally responsible for plant safety – needs to have high confidence (based on good evidence) that the techniques used to check the plant have the necessary capability. It may not be sufficient to rely on assurances from inspection vendors – independent validation is often required. Validation must include any software used to collect and analyse NDT data, as well as mathematical modelling used to predict the capabilities of the inspections. An example of such numerical modelling using a Monte Carlo code to predict radiographic inspection of complex geometries is shown below.

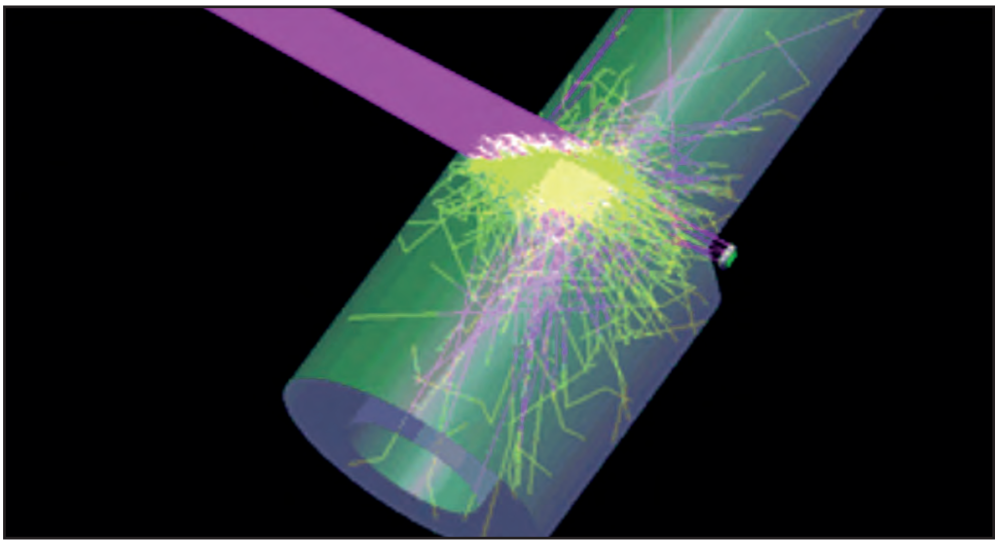


Figure 12. Moderator Code: Developed by EDF, France. (E. Martin, private communication).

Comprehensive validation can take several years (see Figure 11 above) and be costly but potential ways to reduce the time and cost include:

- sharing costs of validation amongst industries with related NDT requirements;
- sharing 'libraries' of test blocks with validation defects;
- building on evidence from earlier validation programmes;
- international sharing and recognition of validation evidence.

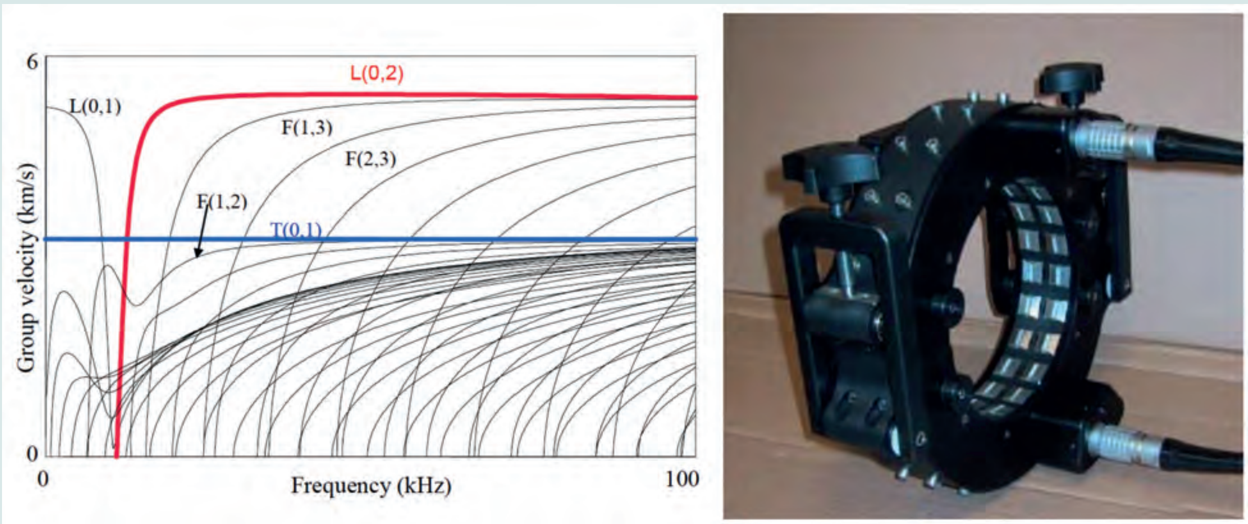
The European Network for Inspection and Qualification (ENIQ) has been successful in introducing a common validation methodology that is accepted throughout the European nuclear industry. Another widely accepted approach to validation is the Performance Demonstration Initiative (PDI) administered in the USA by EPRI to meet the requirements of ASME X1 Appendix VIII. In the aerospace industry, a different approach based on probability of detection (POD) has been developed. All these approaches to validation have been operating for over 20 years, but there is still scope for the efficiency opportunities listed above.

Whether or not formal validation is required, there is still a need for wider understanding of the capabilities of techniques and recognised standards for emerging technologies.

Human and organisational factors, such as the quality of procedures, training and supervision are also important for reliable NDT (E Martin Ref. 2).

Box 3: Example of timescales for research and development: ultrasonic guided waves

One example of typical timescales concerns the introduction of ultrasonic guided waves which are routinely used for identifying damage in industrial plant (for example corrosion in pipelines). Initial research to understand the modes of propagation of ultrasonic waves required for screening long pipes was undertaken around 1979. Full research and development began around 1990, and a commercial system became available by about 1995. Several commercial systems are now available and further research and enhancement of capability continues actively today.



Theoretical analysis of ultrasonic wave modes in pipes and an early, rigidly clamped transducer system (courtesy of Cawley *et al.* Imperial College)

Box 3 continued overleaf

Box 3: continued

Commercial guided wave systems inspecting structures in arduous conditions (courtesy of TWI).

Section 6

Ways of encouraging better appreciation of NDT and more sustained funding

If the value of NDT is to be fully appreciated, industries, universities and NDT societies need to be proactive. Initiatives to consider include:

- Publicising case studies demonstrating the benefits of NDT and showing numerically that the value of increased safe service life of infrastructure can be much greater than the costs of NDT;
- Fostering closer links with related engineering disciplines and with the wider engineering community, including insurers and regulators in addition to research funding organisations;
- Raising the profile of NDT throughout the education system including postgraduate, undergraduate and engineering apprenticeships. Mentor arrangements and travel grants can be especially beneficial for early stage careers (ICNDT has a Working Group reviewing these aspects).

A wider understanding of the benefits of NDT is likely to improve the prospects for sustained funding of research and development in NDT. However, there are additional initiatives that are likely to have considerable positive effects:

- Articulate forward visions of NDT for five, ten, and 20-year horizons;
- Encourage funding for technology transfer and standards as well as basic research;
- Demonstrate the value of national and international cooperation on NDT infrastructure, for example standards, validation methodologies, libraries of validation samples.

If the benefits of NDT are to be delivered, there are a number of Critical Enablers:

- Increased international cooperative research – with full industrial and academic participation;
- Industry consortia willing to share knowledge and expertise as well as costs of research and development;
- Adequately funded centres of NDE expertise for research, development and validation of new techniques;
- Training and education at all levels from apprentice to doctorate;
- Increased awareness of the opportunities for exciting careers in NDE for those with practical skills applying the techniques, through to academic researchers driving the technology forwards.

One example of how universities and industries may cooperate on NDT research and development is given in Box 4 – the UK Research Centre for NDE (RCNDE). Other examples of successful cooperative programmes include the Centre for Nondestructive evaluation (CNDE) at Iowa State University in the USA; the Indian Centre for NDE (ICNDE) in Madras; and the Federal Institute for Materials Research and Testing (BAM) and Fraunhofer Institute for Nondestructive Testing (IZFP) in Germany. In France, CEA and EDF have important NDT research and development programmes which include universities and equipment manufacturers.

Section 7

Conclusions

- NDT is an essential engineering service to reduce risk of failure throughout the whole lifecycle of a plant or component.
- Technologies must be effective and deployed by suitably qualified individuals.
- As engineering infrastructure ages and more complex systems are built, the need for increasing NDT capability is increasing.
- Investment in research and development and skills to advance NDT will assist economic growth for many industrial sectors.
- Timescales for introducing new technologies are substantial, and medium- to long-term visions and strategies are required so that NDT research and development can progress alongside the introduction of new materials and processes.
- More data and evidence, including case studies, would help to support these conclusions.

Section 8

Recommendations

1. Articulate forward visions, led by industry, of NDT for 5, 10 and 20-year horizons and encourage research and development programmes which match the visions.
2. Seek to establish funded research and development networks involving all key players: centres of expertise, universities, government, industry and insurance.
3. Seek to establish funding routes for technology transfer including validation and standards, procedures and training.
4. Improve awareness of opportunities in NDE and provide suitable education and training at all levels: apprenticeships, degrees, postgraduate.

Section 9

References

1. A landscape for the future of NDT in the UK economy. Materials Knowledge Transfer Network. March 2014.
2. Joint ICNDT and Academia NDT Workshop on Importance of NDT Research at 11th ECNDT 2014, 8 October 2014. Presentations available at http://www.icndt.org/Documents/Document-Store?EntryId=15571

Section 10

Acknowledgements

This brochure has relied heavily on the presentations made at the Workshop held at the 11th ECNDT Conference in Prague in October 2014, and thanks are due to all the presenters and the organisers of this workshop and for permission to use the information. Thanks are also due to the Materials KTN for permission to use material from the UK Landscape report on NDT.

Appendix 1: The UK Research Centre in Non-Destructive Evaluation: An example of national cooperation between universities and industries

The UK Research Centre in Non-Destructive Evaluation (RCNDE) is a consortium of universities led by Imperial College London and involving the universities of Bristol, Manchester, Nottingham, Strathclyde and Warwick. The Centre works in partnership with 16 companies across major industry sectors including aerospace, nuclear, and oil & gas. There are also about 30 associate members representing the supply chain. The aim is to develop tools and techniques to detect defects and extend the life and prevent failure of critical UK infrastructure such as pipelines, power stations and aircraft.

Established in 2003, the Centre has grown steadily and recently received a further £5.4 million grant over six years from the UK research funding agency (EPSRC). This will be matched by an equivalent £5.4 million in cash and in-kind contributions from the industrial partners so that the Centre is funded until 2020. International partnerships are also arranged where this is mutually beneficial.

Further information is available at the RCNDE website, www.rcnde.org, an extract of which is shown below, and also from the EPSRC website at: http://www.epsrc.ac.uk/newsevents/news/cableadvancedmaterialsnondestructiveevaluationresearch

Vision and Objectives

The UK Research Centre in NDE links university research with industrial NDE users to create a world-leading centre of excellence in NDE research. It combines innovative science with industrial applicability, with three overarching objectives:

Excellence in exploitable research, building on world-class research, developing new research themes to meet industrial needs, developing overseas relationships, building a critical mass team of interacting scientists and engineers.

Industrial benefit at low cost, directing research at industry's problems, promoting technology transfer from research to application, providing resources for problem solving.

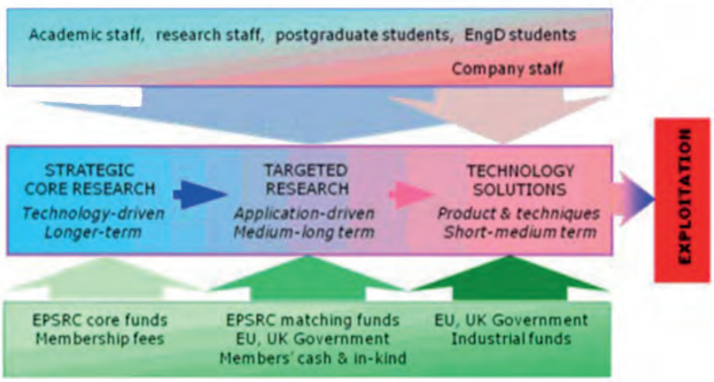
Raising quality of industrial NDE, training highly educated engineer recruits and refreshing the industrial skill base through exchange and networking.

RCNDE has recently added significant new objectives including:

- Develop the next generation of the defect sizing methods required for increasingly stringent structural integrity assessments;
- Exploit scientific advances made in other areas to introduce innovative technology into NDE;
- Develop novel strategies for permanently installed systems to meet the growing demand for structural health monitoring;
- Strengthen links between NDE and mathematics, materials, engineering design, structural integrity & condition monitoring;
- Broaden industrial and academic involvement to include other sectors such as civil engineering.

Research Activities

Research in the Centre falls into one of three main strands as shown in the diagram:



Strategic core research to develop new NDE technologies to build industrial strength in the longer-term.

Targeted research – portfolio of nearer-term projects to meet current and ongoing needs of industry. These are application-driven rather than technology-driven.

Technology solutions – nearer-market sponsored projects to be strongly driven by industrial need. To include development of products and services, and translation of research into technology for industrial exploitation.

Core Research

The current core research programme was designed following an extensive discussion between our academic and industrial members. Industry has a number of generic long-term research needs, which can be summarised as: (1) precursor NDE, (2) more sophisticated NDE, (3) easier NDE, (4) improved delivery of NDE, (5) challenging NDE, reliability & validation of NDE.

EPSRC and industry jointly fund a portfolio of core research projects which address directly or indirectly these needs. Brief summaries and key publications from some of the completed projects are provided below:-

Core research examples

- Next-generation ultrasonic arrays (University of Bristol)
- Super resolution imaging in NDE (Imperial College)
- Laser ultrasonics for detection of damage precursors (University of Nottingham)
- Advanced thermography (University of Bath)

- New approaches to NDE with micromachined transducers (University of Warwick)
- Permanently installed monitoring of creep damage (Imperial College)
- Nonlinear material inspection (University of Bristol)
- Reconfigurable systems for automated & remote NDE (University of Strathclyde)

A fraction of the membership fee is directed towards increasing the scope of the core programme. Future topics will reflect the research needs of industrial end-users and will be decided by the Management Board.

Targeted Research

The targeted research programme is focused on the medium-to-long term NDE requirements of member companies, as well as fulfilling RCNDE's strategic objectives. Research is co-funded but with very high leverage of public funds throughout. The choice of projects depends on the interests of the members. The Management Board confirms the selection and oversee the projects on behalf of the members.

EPSRC typically provides 50% of the total funding for these projects and funding will also be sought from other government schemes where appropriate. Some of the targeted research projects have involved collaborative research with universities outside the main academic consortium to broaden the scientific resource.

Where synergies are identified between members' requirements and organisations elsewhere in Europe, the Centre seeks to set up international collaborations in order to apply for EU funds. The Centre also seeks collaborations further afield where there are clear benefits to the Centre.

Technology Solutions

The third main RCNDE area of activity is strongly industry-driven R&D to generate credible solutions to NDE problems. It includes feasibility and problem-solving studies, product development, and technology transfer.

If requested by members, RCNDE sets up sponsored projects and uses its experience to bring them to a successful conclusion. If a NDE need is best met by downstream collaborative R&D, then the Centre can initiate joint industry projects. Such projects often qualify for matching funds from UK Government or the EU.

If the project is concerned with exploitation of research, RCNDE can help translate technology into useful solutions, either in the form of products or of services. There could be broader collaboration, for example, with instrumentation, service companies or RTOs, or it may require the formation of a spin off company.

The UK RCNDE has been successful in demonstrating the value of a coordinated programme which integrates basic (core) research, work targeted at longer-term industrial problems, and investigation of specific needs of industrial members. The benefits include:

- Rapid access by industrial members to the latest research and to the researchers' expertise;
- More reliable public funding based on a stable, non-exclusive consortium of universities;
- Valuable cost-sharing amongst government funding bodies and industrial partners;
- Critical scrutiny of the overall programme avoids duplication and maximises research benefits.

A Centre for Doctoral Training has close links with RCNDE and offers Engineering Doctorate or PhD courses in NDE.

Question: Could this example of cooperative research be a useful model for other countries or regions?

Published on behalf of ICNDT by the Publishing Department, The British Institute of Non-Destructive Testing,
Newton Building, St George's Avenue, Northampton NN2 6JB, UK.
Tel: +44 (0)1604 89 3811 | Fax: +44 (0)1604 89 3861 | Email: info@bindt.org | Web: www.bindt.org

www.icndt.org