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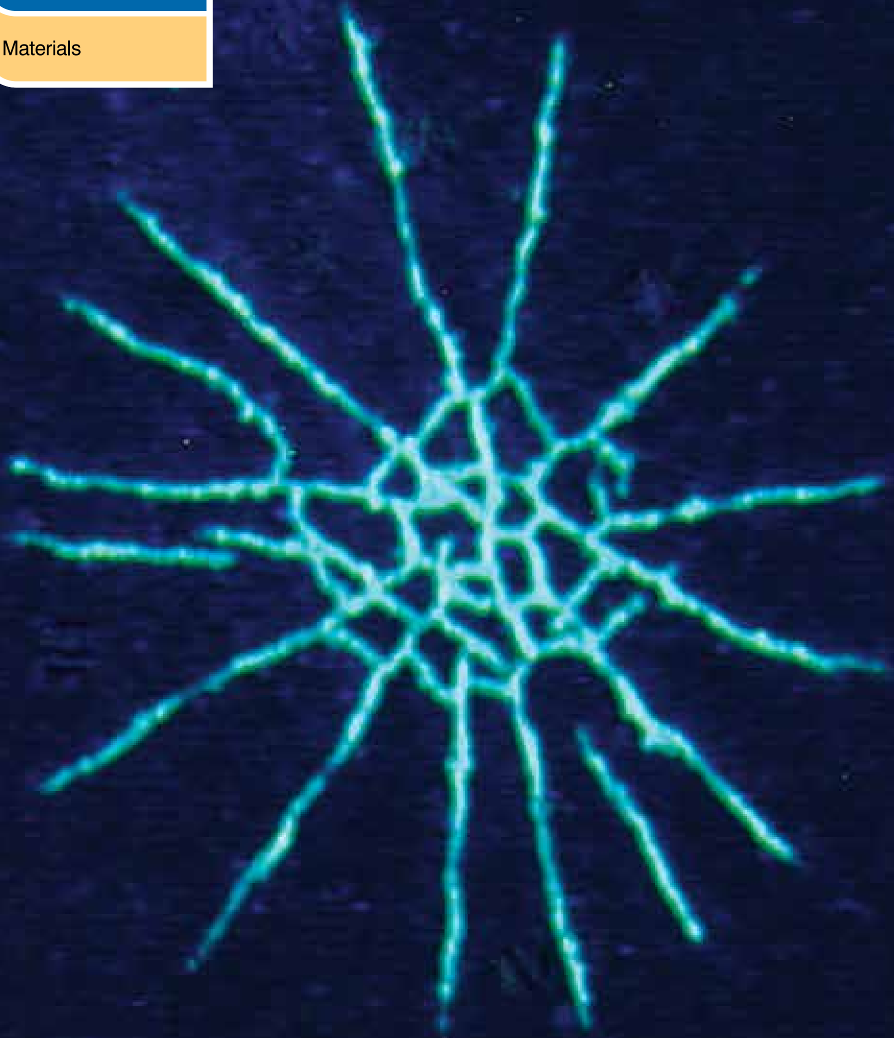

A LANDSCAPE FOR THE FUTURE OF NDT IN THE UK ECONOMY

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ABOUT THIS REPORT

Non Destructive Testing (NDT) employs sensor and imaging technology to assess the condition of components, plant and engineering structures of all kinds during manufacture and in-service.

NDT covers a range of technologies and is known under a number of abbreviations. For simplicity this report uses the term NDT to include Non Destructive Evaluation (NDE) and some aspects of the related technology of Condition Monitoring (CM).

This report was edited by the NPL Product Verification Programme and the Materials Knowledge Transfer Network, with members of the NDT Working Group, based on a series of sector reports generated in 2012.

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The front cover shows a crack pattern in a Chrome plated steel test piece revealed using a fluorescent dye. This is from a control test pieces used, on a daily basis, in manufacturing to demonstrate the dye penetrant NDT process is performing correctly. Photo courtesy Rolls-Royce plc.

If you don't have much time then look at the 5 minute read

EXECUTIVE SUMMARY

Non-destructive testing (NDT) is an important and growing industry involving R&D, sensor and instrumentation supply chains, and a service-provision sector. The community has formal mechanisms for skills development from practitioners to Doctorate level.

This report, compiled by a cross-sector, industry-academic working group, identifies the key opportunities and challenges for the UK NDT community.

NDT is in itself an important and growing industry involving R&D, sensor and instrumentation supply chains, alongside a service-provision sector. When deployed to best effect as part of the complete engineering design process, it delivers safe, reliable and long lasting structures such as power stations, aircraft etc.

Every day more than 25,000 inspections are carried out in factories and on-site in the UK to detect defects and damage in a huge range of products, plant and structures; it is estimated that there are more than 120,000 inspectors operating worldwide. The community has formal mechanisms for skills development ranging from practitioner to Doctorate level.

The global NDT industry had an estimated turnover in 2012 of about $5.6bn. This levers a much greater benefit to end users through intelligent risk management.

Regulatory bodies demand that NDT is used to demonstrate compliance with safety and other legislation, and for unregulated industries the commercial advantages of reduced warranty claims, improved plant reliability and higher customer satisfaction justify its use.

NDT delivers high impact in terms of safety, asset value maximization and competitive benefits for client industries such as aerospace, power generation and transport. Making the most of available benefits in the future requires planning now to allow effective navigation through the landscape of change which lies ahead. 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.

As such NDT will have important roles to play in at least 5 of the 8 UK Government 'Great Technologies' and impacts on all of the National key competences defined by the Technology Strategy Board (TSB) in its High Value Manufacturing Strategy. The UK has traditionally been strong in NDT technology and UK R&D organisations are relied upon by major global players. UK training and certification in NDT are seen as the international gold standard. Industry is actively supporting NDT innovation at all stages, involving collaboration with Research Councils and the TSB Catapult centres.

The report concludes by recommending the following high level actions:

- Strengthen business engagement and education
- Attract and up-skill new entrants to solve the demographic gap and deliver advanced NDT solutions
- Maintain and extend the existing joined-up R&D portfolio (Technology Readiness Level - TRL - 1 to 3)
- Enable a step change in the speed of technology transfer into wider business sectors (TRL 3 to 6)

ACKNOWLEDGEMENTS

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CONTENTS

5 MINUTE READ

This report describes the current status of the NDT industry and has been compiled by sector experts. It highlights the opportunities and blockers for UK NDT over the next 20yrs.

WHAT IS NDT?

- Most structures contain defects or damage and Non-Destructive Testing (NDT) and Condition Monitoring (CM) are the tools used to detect and monitor them to keep our infrastructure safe and operational, often beyond their original design lives. Over 25,000 inspections are carried out every day in the UK alone.
- Cracks and flaws can be formed during new manufacture and defects such as fatigue and corrosion damage develop during service. The NDT techniques used by industry are designed to detect reliably the defects that matter. When deployed to best effect, there is a strong link between the NDT detection capability, the design of the structure and the duty cycle it undergoes. Intelligent interpretation then fixes the inspection interval so there are typically at least 3 chances of detecting a critical flaw. Where regulation is not imposed this link can be weak with the risk of over-sensitivity or worse, allowing critical defects to go undetected.

WHO USES NDT?

- NDT is a key capability in assurance of products for aerospace, power generation, and defence, to name a few. More detail for each of the 12 sectors surveyed are shown in the main table of this report of this report
- NDT plays a significant role in High Value Manufacturing as it establishes the fitness for purpose of new and service run parts. Modern and evolving techniques are capable of inspecting complex shapes and by linking the detection capability to the duty cycle, parts will perform reliably with predictable service intervals.
- NDT has a direct impact on 5 of the 8 UK Government 'Great Technologies' and all of the 22 National competences for High Value Manufacturing highlighted by the Technology Strategy Board (TSB), as shown in Annex 1.
- Involving NDT engineers during the development phase of new materials, processes and engineering structures, allows timely development of any new techniques required and optimisation of inspection both during manufacture and in-service.

WHAT IS THE UK'S MARKET POSITION?

- The global NDT industry had a turnover in 2012 of about $5.6bn, for both products and services.
- The UK has 24 of the 183 key NDT companies, with the US at 75, Japan 4, France 10, Germany 20, rest of Europe 27, Asia (excluding Japan) 20
- The UK is world-leading in NDT development, has a NDT presence in the nationally funded Manufacturing and Catapult Centres, and a healthy supply chain including training organisations that operate internationally. The professional Institute, BINDT, and TWI manage training and qualification schemes for all industry sectors. Inspectors qualified to UK standards are recognised as 'world's best'.
- The NDT market dynamic shows a small number of consolidated international players, with a pool of niche technology, product and service providers which are accessed opportunistically. This is generally stable, but when a new technology is developed, new business opportunities are created. The UK's strong R&D pool is providing a good source for this renewal.

BARRIERS TO GROWTH

- All defect detection processes must be reliable, requiring NDT methods to be validated and performed by trained inspectors to recognised standards. Validation, training and standards development activities are expensive and slow the time to market for new NDT technology. A classic example is the ultrasonic Time of Flight Diffraction technique developed by 1985 which took over 20yrs to become mainstream. This typical market failure in bringing new techniques to fruition arises from the high cost of validation due to the need for large numbers of realistic defects in relevant samples and environments. If this is overcome the capability, standards and training requirement are defined and the technique can be used globally, resulting in new long term business opportunities. The high cost of validation is

Above: NDT being performed in the 'splash zone' on a North Sea oil rig

Below: NDT inside a jet engine. Cracked compressor blade detected using fluorescent liquid viewed under UV light.

illustrated by the recent example of a technique that took 4years to develop, cost £60k to design but £400k to validate for one type of aero engine turbine blade.

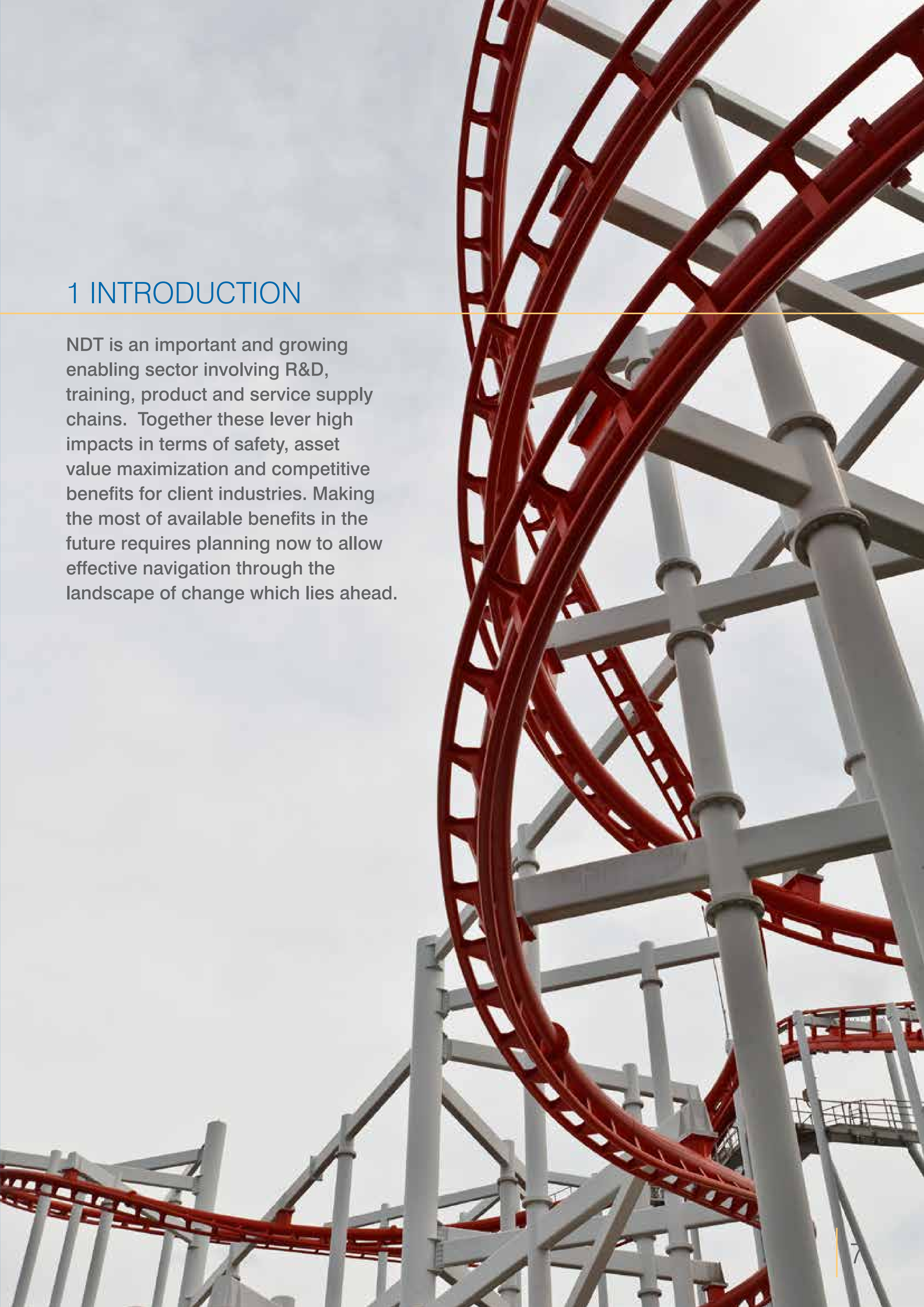
- For business models that do not include through-life ownership, NDT is often seen as a burden. However, as soon as the total running costs of a structure are included, NDT and CM are key to maximising value and extending useful asset life.
- NDT technologies can become buried in companies who have done the validation for a specific task, but do not publish the work: anyone else wishing to use the method would have to pay again. Having a national organisation to deliver these vital steps would accelerate and de-risk the delivery.
- A 20yr Industry vision for NDT development has been produced, including the ability to inspect new engineering materials and designs, increased automation and ultimately self monitoring structures. The academic community is being funded to deliver the required technologies with an EPSRC/industry Strategic Partnership for NDT, the Cranfield Condition Monitoring Centre and TWI as particular hubs.

ENABLING ACTIONS REQUIRED

- New business engagement – Demonstrate the value of NDT through the life of a facility or structure. Engage insurance companies and regulators to maximise the benefits of NDT.
- People – The NDT sector has a skewed demographic of over 45yr olds and needs to raise its profile within the education system. NDT is a very practical profession and can usefully develop people with minimal formal qualifications, but equally there is a growing gap of skilled personnel as new technology reaches the market.
- Technology – Existing end users have defined a 20yr cross sector vision for NDT development. The UK is well placed with development groups such as Cranfield, TWI and RCNDE to deliver this, provided the work is focussed on achieving the vision.
- Validation – The high cost is usually too great for many first adopters so a national focus to deliver this vital step would de-risk the delivery of new technologies and accelerate business growth. A National Defect Centre/Library would greatly reduce the cost.

1 INTRODUCTION

NDT is an important and growing enabling sector involving R&D, training, product and service supply chains. Together these lever high impacts in terms of safety, asset value maximization and competitive benefits for client industries. Making the most of available benefits in the future requires planning now to allow effective navigation through the landscape of change which lies ahead.



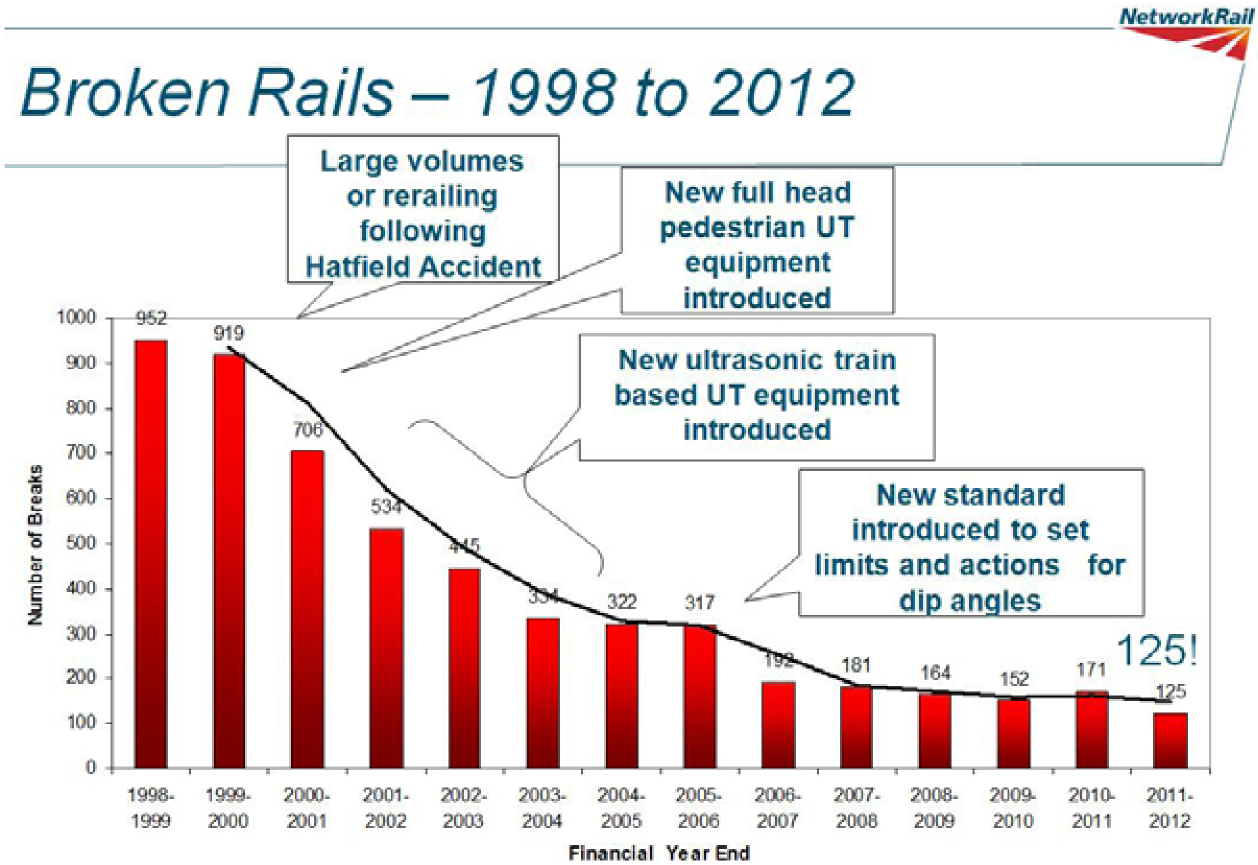


Figure 1

Network Rail introduced effective NDT onto the track and have successively reduced the number of rail breaks/year increasing network performance. This approach has been exported to other national networks. Courtesy John Harris – Network Rail.

2 SCOPE OF NDT

NDT encompasses the inspection technologies used to detect defects and harmful changes in any structure, common methods being radiography, ultrasound, magnetic, dye penetrant, eddy current, thermal and visual though many other physics based methods are also used.

Most structures contain cracks, corrosion and damage which often become worse with time. There are some classic benign examples, such as the crack in Big Ben which occurred in Sept 1859 and has hardly grown since, while others have grown fast and led to many catastrophes: Hatfield, Flixborough, Piper Alpha, to name but a few. NDT is the engineer's tool for detecting these defects, keeping our infrastructure on the land, sea, air and in space operational and safe. Every day more than 25,000 inspections are carried out in factories and on-site detecting cracks in the UK. Large numbers of monitoring systems are in place 24/7 on bridges, generators and engineering plant.

The evolution of cracks, corrosion and damage depends on the duty cycle of the structure, and teams of Material, Stress, Integrity and NDT engineers are involved in defining each inspection which then needs to be reliably carried out.

Figure 1 demonstrates the impact of NDT on the rail system. Prior to the Hatfield disaster rail breaks were running at about 900/year on the UK network. When suitable NDT was applied, in this case an ultrasonic technique, the rate was reduced. Through progressive improvements in the NDT technique further reductions have been achieved. This asset management system has now been exported to other national networks.

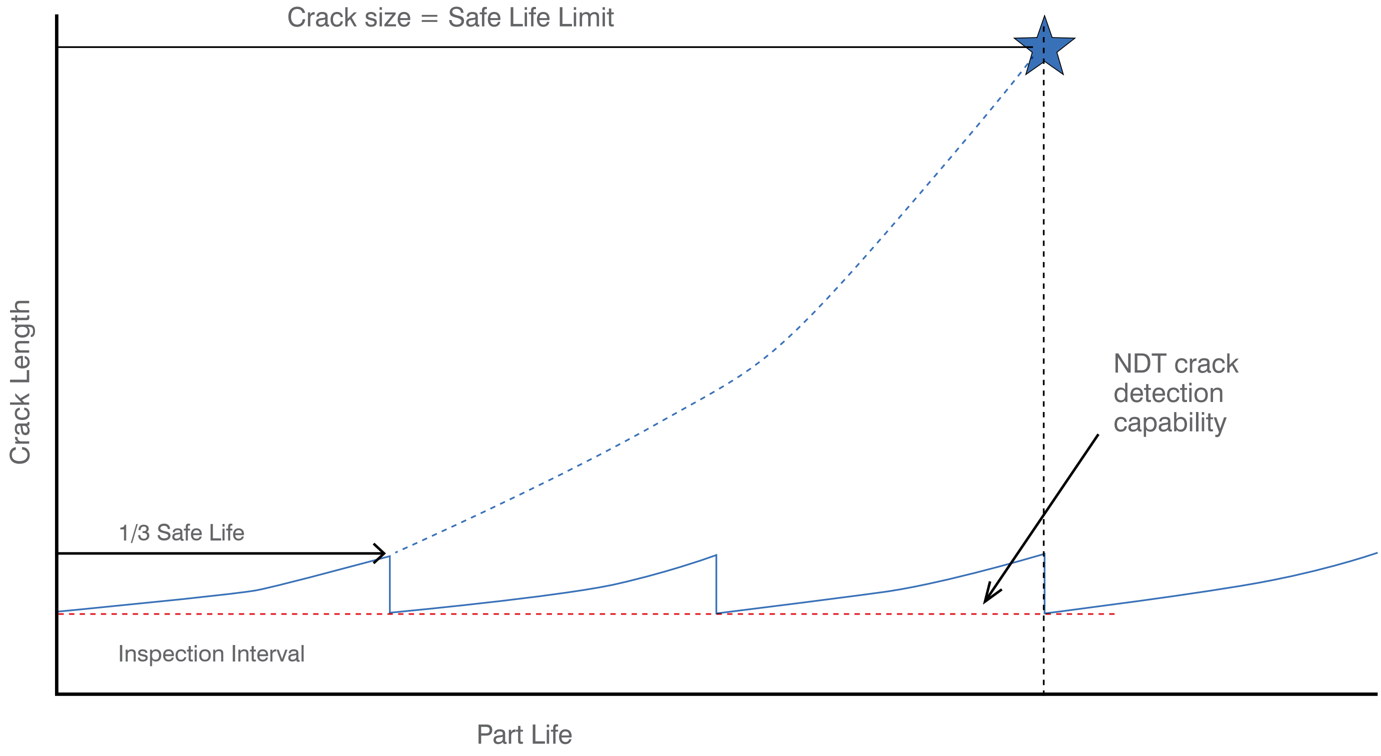


Figure 2

Diagram showing effect of NDT process on cracks in a structure.

Inspection interval is set by the time taken for a crack to grow from the smallest size the NDT method can reliably find and the size at 1/3 of the Safe Life. This allows additional safety in that any crack that may be missed would have 2 other opportunities for detection

3 THE IMPORTANCE OF NDT

Improved NDT capabilities are central to raising the quality of engineering materials and to the safety assurance of engineering structures. NDT is therefore a vital ingredient for the safe and sustainable future of UK industry.

3.1 NDT IN NEW MANUFACTURE

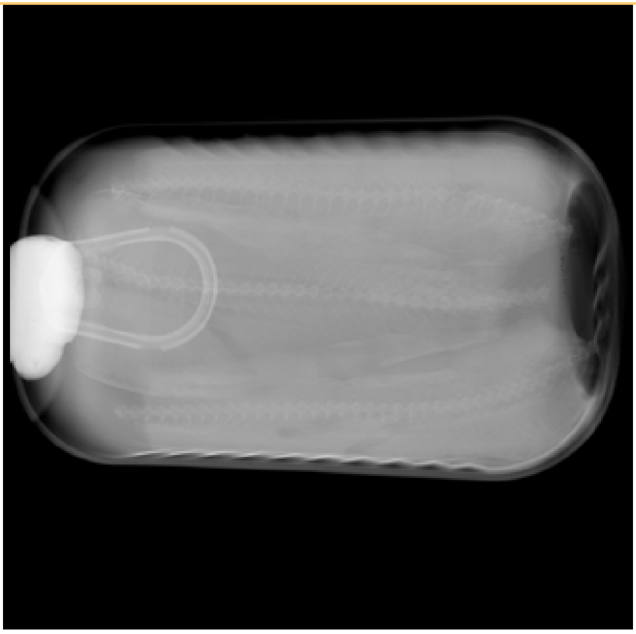
Defects can arise in materials processing and manufacture. For critical components, such as aeroplanes and engines, nuclear plant, ships and satellites NDT is used at virtually every stage in the manufacture to ensure the final product is free of any harmful defects. The techniques used have to match the level of detection required to confirm integrity. Increased product reliability can be delivered by taking full account of the duty cycle, the material properties and the inspection capability during the design process. This has been successfully achieved where the Damage Tolerant Design philosophy is used, notably in aircraft design such as for the Joint Strike Fighter.

To achieve reliable performance the inspectors are trained and reassessed through controlled personal qualification schemes. Regulatory bodies demand that NDT is used to demonstrate compliance with safety and other legislation, and for unregulated industries the use of NDT is justified by the commercial advantages of reduced warranty claims, higher customer satisfaction and a reputation for reliability.

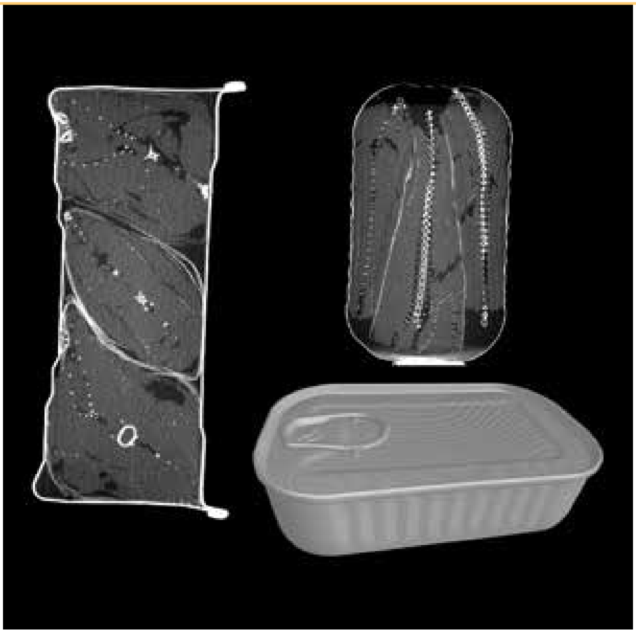
3.2 NDT IN THROUGH LIFE MANAGEMENT

Through a product or plant's operating life its integrity will deteriorate and the overhaul intervals are dictated by the capability of NDT to find many types of defects such as corrosion, erosion, cracks and creep damage reliably.

Defects can grow to cause failure and professional through life management uses NDT capability to set the inspection intervals to match the expected defect growth rate. This is illustrated in Figure 2, showing a typical inspection cycle linked to crack growth. Frequently this inspection interval dictates the timing of the overhaul cycle for a plant cycle, such as power station outages.



Conventional x-ray of sardine can



X-ray CT image of a tin of sardines. This 2008 3D image shows the improvement in capability over the conventional x-ray opposite.

3.3 NDT IN NEW DEVELOPMENTS

NDT is crucial for the development of new manufacturing methods, materials and designs. Defect mechanisms need to be identified and understood during the development process so that these developments can be improved to minimise defects in the final products. This exercise also creates the opportunity for the NDT processes to be developed to meet the challenges of these new materials, shapes and structures.

Composite materials are a classic example where NDT methods such as x-ray computer tomography (x-ray CT), in which the UK has a world lead, have been developed and applied to create new inspection standards and processes.

3.4 NATIONAL INITIATIVES

In 2003 a UK Research Centre in NDE (RCNDE) was set up by EPSRC and 5 sponsoring companies to co-ordinate the national research effort into NDT and this has now developed into a group supported by 16 major companies from most sectors with 30 Associate members representing the supply chain. A strategic partnership between the end user companies and EPSRC was established in 2010 to focus on the delivery of this capability. The industrial group has generated a vision document describing the NDT capability required in 5, 10 and 20 years time for each market sector [1]. RCNDE is delivering NDT solutions, and is now funded until 2020.

As a key element in high value manufacturing, NDT features in many of the EPSRC Research Centres for Innovative Manufacturing. In addition, the Technology Strategy Board has invested in state of the art NDT capabilities in its High Value Manufacturing Catapult, notably at The MTC in Coventry, the NCC in Bristol and the N-AMRC in Sheffield. The Transport, Future City, Connected Digital Economy and Off-Shore Renewable Energy Catapults will also have reliance on NDT.

The related area of Condition Monitoring is likewise significant, with clear potential to impact National initiatives such as the Integrated Vehicle Health Monitoring Programme at Cranfield University.

NDT impacts on 5 of the 8 UK government priority Great Technologies – especially advanced materials and robotic & autonomous systems, together with all of the national competencies for High Value Manufacturing identified by the Technology Strategy Board as shown in Annex 1. NDT is also already involved as a key enabler in the growth and innovation strategies identified by BIS in its 2012 Growth Strategy.

1 P Thayer, Insight Vol 54 March 2012

4 A MARKET OVERVIEW

4.1 THE GLOBAL MARKET

The global NDT/NDE industry had an estimated turnover in 2012 of about $5.6bn, including both products and services[2]. The overall drivers were in maintaining and assuring the safety of key infrastructure, and although the financial crash of 2008 may have limited growth in other sectors, NDT/NDE maintained growth of about 3.2%, and growth is returning strongly, as expressed by a practitioners' survey[3] in the USA.

The major markets are in energy extraction, transport, power generation (conventional and nuclear) and in aerospace, with emerging but significant contributions especially from new markets such as renewable energy. Underpinning all this is a market in R&D, equipment and service provision, professional training and certification.

4.2 THE UK MARKET

The extent of the current UK market is not yet well quantified but the UK national institute (BINDT) has 172 company members covering the equipment supply, training, service and end user sectors. This constitutes the majority of the commercial organisations involved in NDT in the UK. The manufacturing sector employs large teams of trained NDT inspectors as most parts are inspected multiple times through the manufacturing and service cycle. Plant operators (eg Oil & Gas, power generation and transport) employ NDT specialists to manage and perform inspection, and often procure NDT services from the supply chain.

The UK has traditionally been strong in NDT technology and innovation, but in common with many other nations, the supply chain has seen a significant consolidation of players into a few transnational groups (GE Inspection Technology, Doosan, Olympus NDT, Oceaneering, Intertek etc). There are still robust niche players offering unique capabilities, and in fact, the UK punches above its weight, supplying, according to a survey by Global Industry Analysts[5], 24 key companies, from an international pool of 183. Figures for other regions are:

Sector	NDT linkage	UK Growth %/annum
Energy	High	2.5
Nuclear	High	4.0
Aerospace	High	4.8
Automotive	Medium	3.2
Renewable	Medium	12.5

Table 1

The key sectors where NDT is focused are high growth both globally and in the UK[4]. Transport and aerospace are export intensive sectors. Realising this growth cannot occur without NDT as an enabler

USA 75, Japan 4, France 10, Germany 20, Rest of Europe 27, Asia Pacific excluding Japan 20 as shown in Figure 3.

In particular, UK training and certification are seen as international gold standards. UK R&D centres are relied upon by major players as shown by the long term industrial engagement with bodies such as the UK Research Centre in NDE (RCNDE), TWI and the long running Oil & Gas joint industry HOIS programme.

The potential for the UK market will be controlled by access to the key global growth sectors, (Table 1) as well as through exploitation of the improved benefits from emerging technologies. UK NDT products and services are also deployed globally by end users, magnifying the impacts for the UK economy.

4.3 KEY SECTORS

Each end-user sector has its own NDT technical focus, driven by the relevant plant, materials and operational environments, and each sector has associated technology and market dynamics which are distinct from others.

This report draws on data from the acknowledged contributors. Section 4.6 summarises the status of NDT in each sector. Where specific aspects are unknown this is stated, but where possible quantitative data are provided. The information in 4.6 is provided for the Insurance, Aerospace, Rail, Marine, Civil Infrastructure, Power, Oil & Gas, Advanced Manufacturing and Defence sectors together with the NDT Equipment and Service supply chain.

2 This is derived from published reports but also includes confidential company data provided during the sector reviews

3 http://www.pqndt.com/NDT-Salary-Survey/PQNDT-2011-Salary-Survey.pdf

4 BIS economics paper No 18: Industrial Strategy/UK sector analysis

5 http://www.frost.com/sublib/display--market--insight--top.do?id=223778470

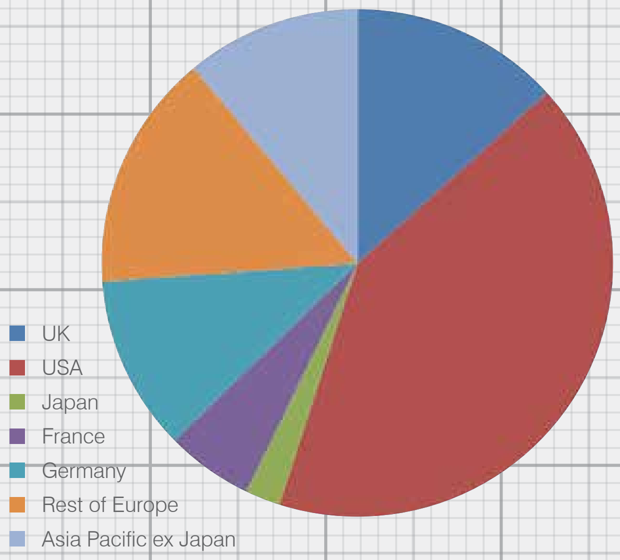
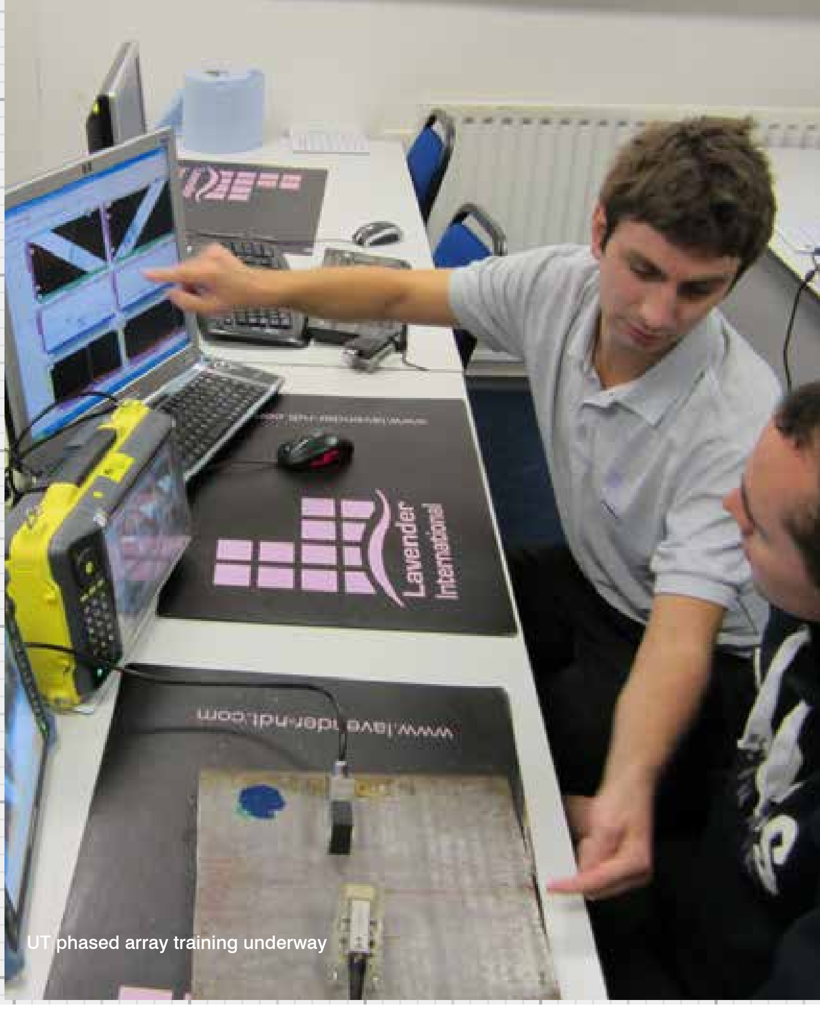


Figure 3

Global distribution of 180 Key NDT supply companies'



UT phased array training underway

Cross sectoral themes which are drawn out from the sector review include:

- Training – NDT involves the practical application of various scientific principles and the industry accommodates almost the full range of academic abilities, with appropriate training provided at each level. Training providers are important for building relationships and driving best practice across market sectors. Key training challenges include increasing IT literacy and raising skill levels for application of new inspection technologies – from inspection practitioners to doctoral level engineers.
- R&D – maintaining and growing a strong UK R&D capability is essential to provide new technology to meet defined future industry challenges, and to deliver the core skills needed to support the adoption of emerging technologies as well as rejuvenating an ageing community.

4.4 MARKET DYNAMICS OF THE NDT INDUSTRY

Generally, the NDT sector has a small number of consolidated international players, with a pool of niche technology, products and service providers which are accessed opportunistically.

This situation is generally stable except where a given sector develops a new technology, in which case a new business may be created. Such opportunities are emerging particularly in the renewable energy and aerospace sectors, driven by the need for material and scale innovation. Growth territories include Brazil, the USA and the Far East.

4.5 GAPS AND BARRIERS

Analysis of the industrial landscape reveals there are two main areas or gaps which have held back full exploitation of the benefits available from NDT: timely technology transfer of new techniques and market perception of the value of inspection in some quarters. For the future, there are two additional potential barriers: the need to maintain or grow investment in R&D and the increasing skills gap due to an ageing workforce and the need to adopt more advanced NDT technology. Understanding and dealing with these gaps will lead to new opportunities for the industry as explained in the following paragraphs.

Technology transfer

When a new inspection technology is developed by academic R&D or by the supply chain (often by SMEs), it will not be adopted widely by end-users without first being validated and without adequate standards back-up. Validation is very costly and in the current environment standards take many years to generate. Cultural barriers exist in some sectors and change is traditionally slow in NDT.

Examples include the ultrasonic Time of Flight Diffraction technique for accurate crack depth measurement, which was developed by the Harwell NDT Group in 1985. It then took over 20yrs for a standard to be produced allowing it to move from niche to general use. The high cost of validation is illustrated by a typical example of an ultrasonic technique for turbine blade inspection which cost £60k to adapt the science and a further £400k to deliver as a validated technique over a 4 year period.

If an inspection technology is developed or validated by an end user, the technology can become 'buried', either deliberately to maintain competitive advantage, or through the high cost of delivery as noted above. An end-user (or sponsor) will usually only fund validation of the method for their own application. The cost of validation and the generation of standards is prohibitive for SMEs (supply chain or spin-outs from universities).

Strengthening the technology transfer through imaginative routes for funding technique validation and fast-tracking standards development would unlock new commercial opportunities.

Perceived market value

While many high technology businesses fully recognise the value of NDT, some end-users fail to assign appropriate value to NDT. Inspection developments then tend to be a reaction to a critical failure/catastrophe, rather than part of a considered asset management approach.

There is a need to demonstrate to those companies not already engaged with 'smart' NDT that significant value can be created at New Manufacture (e.g. process optimisation, reduced wastage and warranty costs) and through-life Asset Management (optimising performance, reducing downtime and life extension).

An important issue is to overcome the existing weak links that are often found between company functions dealing with defining the duty cycle of a part or structure, the inspection strategy and the structural integrity requirements. The activities of the NPL Product Verification Programme are a relevant new initiative here.

R&D Investment

The role of developing new and existing NDT processes is to deliver the inspection capability required by industry and to improve the understanding of the capabilities and limitations of NDT for specific applications. Such rigorous development typically requires major effort which most companies today cannot finance alone. Traditionally large engineering companies had internal NDT research groups developing inspection methods to meet their current and future requirements. During the 1980's and 1990's, the various economic cycles and privatisation of former public sector industries led to a dramatic slowdown in industrial NDT research with significant consequences for innovation.

The EPSRC-industry initiative to establish RCNDE in 2003 has helped to rebuild the UK research base into a world leading resource. However, very significant long term research is still required to meet the long term industry vision for NDE set out in Section 5.2 so that the level of overall research investment needs to be maintained or grown over the coming years.

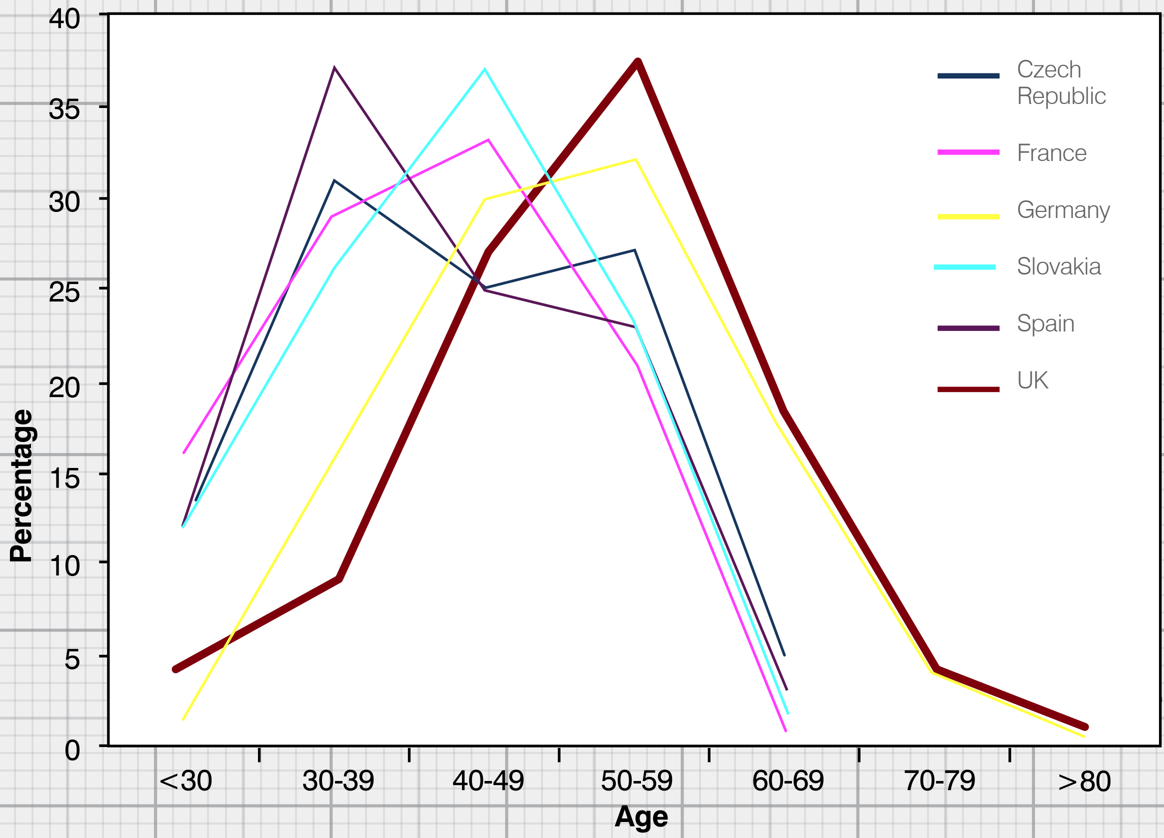
People and Skills

NDT inspectors are qualified in the techniques they use and the UK has a strong network of NDT schools delivering training and examination both here and overseas. NDT is a very practical activity and the business offers opportunities to a wide range of skill levels through its structured qualification system. NDT Level 1 qualification allows inspections to be carried out, Level 2's can inspect and interpret the results and Level 3's design the inspections. Regular, often annual, recertification is required to ensure the skill level is maintained. One severe limitation is the lengthy period of experience that is required for an individual to become fully qualified. The minimum is 1 month for visual methods and this extends to 9 months for the more complex methods such as x-ray and ultrasound. The experience is required to ensure a full understanding of the technique's limitations and capabilities across all the applications but is an expensive burden for some organisations, though ideally suited for modern apprenticeships. For the more qualified, the profession offers degrees from Foundation to Masters and both PhD's and Engineering Doctorates are currently available to advance the science and transfer knowledge from the academic sector into industry.

The UK is well placed in the training and certification sectors as the UK schemes such as BINDT's PCN and TWI's CSWIP are internationally recognised as world leaders. Other national NDT Institutes operate training schemes and there is an initiative to harmonies these through the worldwide International Committee of NDT (ICNDT). Another major national scheme is ASNT (American Society of Non-

Figure 4

Professional age Profiles in the NDT industry Courtesy BINDT



Destructive Testing) which operates a company based system allowing specialist processes to be used; this is commonly the case for the aerospace Industry.

A review of national NDT Institute membership and qualified NDT inspectors across some European countries was carried out in 2007, Fig 4. This shows the UK as having the oldest demographic with 60% of its 1600 BINDT members over the age of 50 and 13% under the age of 40. The population of inspectors is more balanced but requires a greater number of new starts than is currently being achieved. The 2013 estimate of qualified inspectors in the UK is 35,000 based on extrapolating the PCN data with a current newly qualified rate of about 500/yr. Recent growth has been seen with an increase in issued qualifications but the trend is still short of the 900/yr new starts needed to maintain the population.

Service companies deliver the majority of site NDT inspections with the large users of NDT inspectors tending to plan their outages in sequence to spread the demand for sub-contractors. This is supported by in-company teams to manage the ongoing inspections. At the current rate of intake the known demographic will result in a 10 to 15% shortage of inspectors and although some reduction is expected by the adoption of new technologies, this is likely to be outstripped by increased demand for the improved capability. Again the UK service sector companies operate worldwide making them well positioned to exploit the growing market opportunities.

A classic illustration of the benefits of NDT is a case where a component in an earth moving vehicle had a high failure rate and the the supplier had to pay penalty charges each time. The supplier took out insurance for these payments, but in the meantime developed an NDT method to identify the defective parts. The failures stopped and the insurance was dropped. The money saved was reinvested to improve the casting process and now a more efficient design has been produced, with the supporting NDT to ensure the quality.

With the rapid introduction of new advanced inspection technology there is a need for increased skill levels, both for end users to understand, specify & use the NDT results and for the suppliers of advanced equipment and services to develop and deliver the advanced solutions. This requires a general increase in capability from advanced NDE technicians, through to PhD/EngD level for research, technology transfer and managing high-tech NDT in end user and supply chain companies. The ageing demographic is particularly significant for the latter group with many professionals approaching retirement. While there are current schemes to train people at PhD/EngD level, these need to be at least maintained and preferably increased to provide a new generation of specialists.

End users

	Aerospace	Insurance	Rail	Marine	Civil Infrastructure	Power (Fossil & Nuclear)
Drivers for the use and evolution of NDT	Safety. Increased service intervals. Reducing tolerance to disruption Low emissions targets New materials	Reducing tolerance to disruption, high utilisation of assets. Fewer engineers. Less redundancy in equipment.	During manufacture to demonstrate compliance with specification and maximising efficiency through in process inspection . During operation to enable effective asset management by delivering greater assurance in safety and reliability between inspection intervals for 24/7 operation. During investigation to determine cause of failure and to manage risk in response to failures. Growing demand is setting the requirement for 24/7 availability to manage passenger and goods capacity.	Classification Society Type approvals and international / national standards apply. NDT used in periodic in-service inspections required for safety critical aspects (corrosion, fatigue, cracks). Smaller commercial and leisure vessels including those using structural composites also bound by standards requiring NDT during approvals or demonstration of compliance with standards.	Need for assessment of ageing infrastructure driven by financial and environmental pressures for better long term management. Trends for incorporating a wide variety of sensor systems within new build and refurbished structures enables both structural performance as well as active and passive management. Innovation in NDT is driven by the continuing trend to use new material and structural solutions in the creation of prestige infrastructure projects.	Ageing fleet - plant life extension and maintaining plant availability key issues. Increased standards in safety and environmental control. Public risk awareness and risk acceptance for nuclear. Next generation plant (fossil & new nuclear) provide new design, access and materials challenges. Source 3 describes the future trends.
Applications	Metal, Specialist alloys Composite parts Coatings Degradation Adhesive Joints	Lifts, hoists, boilers and steam systems, etc.	NDT techniques can be applied to many different types of assets, e.g. rails, rolling stock, bridges and tunnels are subject to regular inspection as part of their management regime.	NDT is applied to hulls at new manufacture for raw material quality and welds and through life for corrosion and fatigue. Composite structures are inspected for manufacturing defects and through life degradations such as delamination and osmosis. Condition monitoring through vibration analysis is often used.	Techniques cover ferrous and non-ferrous metals, cement and concrete, timber, masonry, glass, polymer systems (including fibre reinforced materials) and bituminous products. Implementation is neither uniform nor ubiquitous reflects the level of acceptable risk required by the asset owner.	Pressure systems, steam & gas turbines, rotating plant. Nuclear includes fuel rods, containment vessels, valves, waste containers, waste management infrastructure.
People and skills	16,000 inspectors worldwide. Training requirement well defined. Demographic skewed to >50yr olds. Shortage of qualified inspectors Condition Monitoring capability growing	40 PCN/'shell boiler' qualified UT Practitioners , plus ~100 for in-manufacture inspection	Increasing focus on automating NDT inspection, with significant recent advances in inspecting rails and the permanent way. Much axle NDT remains manual. NDT operators are employed by infrastructure managers and train operators but there is also a significant presence in the supply sector providing a mixture of routine and specialist skills.	Specialist engineer surveyors mostly at graduate chartered/ engineer or technical level often with multi-discipline range of skills able to deal with new processes and technologies. Classification Societies, such as Lloyd's Register, lead and set the technical standards and survey requirements.	Specialist methods supported by a range of organisations , contractors and consultants providing equipment and associated data interpretation. Simple techniques routinely used by individual engineers and technicians. National and industry standards not appropriate across all parts of the sector. Calibration and validation methods frequently not available or are specific and proprietary to an individual sub-contractor.	Inspection management & specialist NDT tends to be in-house, with major use of external contractors. In the UK, it is usual for inspectors qualified in other sectors to be trained for the nuclear sector. At present there is an aging demographic, particularly in the highly skilled and experienced level III group. Experience is key- knowledge less so
Direct Benefits	Safety - to maintain safe flying. Minimised disruption for servicing	Costs of statutory in-service inspection c£2.5 bn pa. The use of improved NDE has the potential to reduce this by c£1bn pa	NDT is core to the effective management of many assets enabling a prediction of remaining operational life. This allows interventions to be planned and deployed in a timely manner, with NDT being used to subsequently monitor their effectiveness. NDT thus helps the industry to assure safety, manage reliability and maximise return on investment.	Economic benefit of extending life of the asset and time between major refits and overhaul. Added safety from ability to measure and predict remaining life of structures and monitor condition of safety critical machinery and systems during service.	Facilitates management of essential infrastructure networks. NDT provides core data required to predict operational life of associated networks. Interventions can be planned and deployed in a timely manner to assure safety, manage risk/reliability, maximise the return on investment and minimise the whole-life environmental burden.	Maximizing safety and plant availability, reducing outage duration and cost, providing reliable information that can be used to justify life extensions or operating power upgrades. Enabling technology for next generation plant and new nuclear build.
Indirect benefits to UK	Business impact of reliable air transport. Business opportunity by providing a worldwide service of trained NDT inspectors. Carbon emissions reduced via optimised designs (smaller safety margins can be justified)	Infrastructure reliability and confidence maintained. There is a business opportunity to extend the risk reduction through NDT with more competitive insurance premiums on civil structures	GB mainline has 32,000km of track and 11,000 passenger vehicles. It delivers 1.25 billion passenger journey per annum covering some 51 billion passenger kms. London Underground with 400km of track carries 4 million passengers a day. The sector moves 12% of land based freight with 21 billion tonne-kms in 2011/12. significant growth and investment. NDT technology and processes are a key enabler of all this allowing the sector to perform more efficiently.	Safety and efficiency are the main business drivers, plus compliance with regulations facilitated by NDT. Marine contributes £19bn to UK PLC and this is increasing with growth strategy towards £25bn by 2020. NDT supports innovation in high value manufacture and through life operation towards higher performance and lower operating costs to maintain competitiveness.	The sector has high employment both directly and indirectly through associated supply chains. The UK is also major exporter of knowledge and technical expertise, and leads in many aspects of infrastructure asset management. The continuing development of a vibrant NDT community providing appropriate, validated, and calibrated tools will help UK infrastructure engineers to remain competitive within the world economy.	Energy supply security. Increasing use of low carbon energy - carbon capture & nuclear.
Technology dynamics	Fast changing	Slow to change	The application and uptake of new technology is relatively slow.	Fluid.	Has been slow to change but becoming more fluid	Fluid as environmental compliance means that various abatement technologies are being fitted to power plants, often bringing new inspection issues and constraints.
Supply-chain dynamics	Stable	Very dynamic - high level of churn in personnel	Stable	Stable	Generally stable but in relation to novel materials and structural systems the situation is more fluid.	Stable

Sources

1 http://www.civitas.org.uk/economy/Energyfactsheet.pdf

2 http://www.oilandgasuk.co.uk/employment.cfm

				Skills		Equipment
Oil and Gas	**Renewables**	**Defence**	**Advanced manufacturing**	**R&D**	**Training**	**Equipment and Services provision**
Increasing focus on safety. Reducing tolerance to environmental releases, pollution etc. (onshore and offshore). More deep-water production Move to 'not normally manned offshore platforms. Very large areas requiring inspection. Increasing amount of aging facilities Full plant availability with minimum maintenance. More sour gas wells in use with high pressure and increased corrosion, especially relevant for Fracking.	Source 1 shows the target of 20% renewable by 2020. This has led to distributed, remote generators and larger turbines using new materials. These are often in extreme and hostile environments. Transition to Structural Health Monitoring (SHM) systems . Marine systems call for techniques that will operate reliably through paint and fouling. Mitigate by more stringent manufacturing inspections.	Need to maintain existing assets and meet safety and environmental regulations	Move to "predict and prevent". Design of components for inspection. Move to automated inspection in manufacture, in semi-continuous rather than batch modes. Environmental constraints on materials, and some NDE technologies like x-ray	Desire to promote the industry as a valuable career. Focus on R&D skills development via Centres for Doctoral Training. Co-operative links with industry sectors to provide resource and path to impact. Industry groups have provided 5/10/20yr vision for DE and many solutions would be effective across all the sectors.	Customers require more computer-literate inspection staff, and more familiarity with up-to-date NDE techniques and equipment. Legacy needs must be maintained to ensure traditional skills base is kept.	Need for protectable IP to strengthen position. Need for routes to access demonstration funding to open new opportunities. Need to keep pace with the changes in materials and manufacturing processes. Sources 4, 5 and 7 gives a quantified description of the sector.
Oil and gas well system and pipelines on land and marine, floating production storage and offloading units, processing and storage units.	Wind turbine towers, generator sets, gearboxes, turbine blades and foundations. Tidal and wave generation systems. Solar-molten salt tanks, pipes and storage systems. Unknown but the burden will rise as the massive numbers of wind turbines being built age. In 2010 the UK had >3400 on and off shore units with a further 1200 being planned.	composites, organics, metallics	High value manufacturing where there is a link between the duty cycle, the material and the quality standard to deliver a reliable part with a known service life or inspection interval.	All of the above, but major focus in Oil & Gas, Aerospace and Nuclear sectors	All sectors, many with specific needs defined in Standardised training and examination requirements.	All sectors
Surface and sub-sea trained inspectors are used worldwide with a growing number of remote vehicle operators required.	Mainly staff working in power sector supporting or transferring into renewables. Specialist skills and services supported by a range of organisations. Specific training and standardisation weak as sector is still young. Smarter monitoring techniques are needed but traditional, people-centred inspections are the norm.	Workforce decreasing, but still about 1000 people are associated with NDT in the UK. Typically recruited as postgraduates and trained in-house	Some individuals within the Catapults are NDT qualified but the skills available cover the full range of methods via accessing the service and the strong links with TWI and the RCNDE	UK R&D organisations, numbering 27 Universities (TRL 1 to 3) and a further ~200 external researchers (TRL 3 to 7) provide not only the technology but also people with the skills and knowledge to exploit it. Since 2008, 80 individuals have left the research groups and taken NDT posts in key engineering companies. Long term support to research groups provides the basis for consultancy services.	Well defined technical training structure delivered by NDT training companies. UK qualification systems used worldwide providing global reach for training companies. New technology adoption being facilitated by professional Institute (BINDT). NDT offers opportunities to individuals with a wide range of academic abilities and the market needs at least 500 new entrants/yr to maintain its population.	Workforce skills cover qualified inspectors, instrumentation design, software skills, production engineering, mechanical design and manufacture, knowledgeable sales teams. The service sector operates worldwide with the advantage to the UK that income streams for work aboard are drawn back to the UK.
The industry tends to work within national and international standards and regulatory frameworks. Plant management is a growing need with erosion and corrosion needing to be managed.	NDT is used to maintain safe operation, reliability and hence availability. Supports scheduling of maintenance and life extension of assets though as these are new structures much time is spent on reactive campaigns to detect new types of defect.	Confidence in Strategic deterrent	Enable sales via whole supply chain	Not quantified- but to give an example, the recruitment of c 140 trained staff pa is seen as key to enabling the new build nuclear programme.	UK training is globally regarded as gold standard US salary survey in 2011 shows a NDT Level 3 earns $104k/yr (Source 6)	Commercially viable businesses, mostly long-lived and high-technology, enabling many high-value sectors. Entry level is progressively through spin-out companies
In 2010, Oil and gas contributed over 1.7% of the UK GDP (source 1). The industry in 2012 is providing employment in the UK for 440,000 people (source 2) Security of UK's energy supply.	The national target for renewable energy is 15% in 2030 (source 3), of which a significant fraction would be wind, marine or photovoltaics. NDT able to support innovative designs and smarter operational practices	N/.a	N/a	UK NDT departments are seen as world class in terms of R&D and have won majority of international awards in recent years. Overseas collaborations often lead to trade links with the UK commercial supply chain.'	UK-trained staff when working abroad bring business back to the UK for the rest of the supply-chain.	Niche suppliers, of which the UK has several, tend to have the market to themselves, so can heavily influence de-facto global standards and technical evolution.
Pressure to reduce costs often means that innovative or risky NDT options are not evaluated. New materials and difficult access bring challenges. Convergence of NDT and CM brings opportunities for smarter NDT to reduce downtime.	Emphasis is on construction rather than Operation and Maintenance. This has led to a piecemeal and reactive approach to emerging operational problems due to novel designs and materials. Sector needs consolidation of experiences and greater integration of Structural Assessment, Materials and NDT functions. Life extension of assets will become as important	Stable	Fluid	Fluid	Fluid, with high investment costs for new technologies and samples.	Stable
A variety of manufacturers, service providers and consultants available, usually supporting multiple industrial sectors. Stable.	Many organisations and suppliers offering perceived solutions to various issues. High need to demonstrate fitness-for-purpose, training and standardisation.	Fluid	Fluid	Stable	Stable	Stable

4 http://www.frost.com/sublib/display-market-insight-top.do?id=223778470

5 http://www.ndtnews.org/News/News_Archive/September_2011/Reports_show_world_NDT_market_has_tremendous_growth_potential.html

6 http://www.pqndt.com/NDT-Salary-Survey/PQNDT-2012-Salary-Survey.pdf

5 A ROADMAP FOR NDT

5.1 APPROACH

In generating this roadmap the following staged approach has been used:

1. 20 year vision - Where does the industry aim to be in 20 years time?
2. Drivers - What are the pressures either on or anticipated to be on the sector during the period ? (obstacles to achieving 20 year vision)
3. Key Enabling Actions - What will the industry need to achieve to deliver the 20 year Vision ?
4. Priority needs - Given the range of actions and timescales/resources, what are seen as the priority needs and deliverables?

(Timescales are Medium= 3-10 years Long = 10-20 years)

5.2 FUTURE VISION FOR NDT

The industrial end-user members of the UK Research Centre in NDE have generated a detailed vision for the future requirements of NDT over 5,10 and 20 year time horizons for a range of market sectors including aerospace, power generation, oil and gas, defence, transport and manufacturing[6] . While there is a wide range of sector specific requirements there are also strong synergies and common themes.

Longer term strategic objectives include:

- More comprehensive integration of NDT data with data from all engineering disciplines to enable structural integrity decisions based on actual operational conditions and duty cycles.
- Far greater application of real-time automated inspection aimed at achieving defect free manufacturing quality.
- The extensive use of online monitoring and smart structures supported by precision-targeted, high performance NDT.
- Greatly reducing the use of disruptive in-service NDT and eliminating it in key applications by combining the use of high fidelity inspection at manufacture and in-service structural health monitoring.

Medium term objectives directed towards the longer term include:

- Improving the quantification of inspection performance and reliability.
- Extending the capabilities of NDT – eg. faster, cheaper and more sensitive inspection.
- Developing inspection methods for emerging new engineering designs and materials.
- Increasing the use of automation and robotic inspection, especially for dealing with difficult access, remote and hazardous applications.
- Engaging with other disciplines (eg structural integrity) to establish the requirements for the information produced by NDT and improve 'Design for Inspection' .

6 P Thayer, Insight Vol 54 March 2012

5.3 DRIVERS

Drivers are defined as 'those factors that could determine sector shape unless other actions are taken' - in particular those affecting the achievement of the 20 year Vision. The Working Group members have identified the following issues as key drivers for the period ahead, based on a series of workshops and meetings with the NDT industry:

- New materials, designs and operating conditions requiring new NDT solutions
- Constrained capital expenditure leading to a growing need for plant life extension again requiring new NDT solutions.
- The need for improved 'Design for Inspection' to maximise product life and user confidence
- Shortage of skilled personnel to address new, high, technology, capabilities generated through successful research and dealing with the ongoing issue of replacing an ageing workforce.
- Demand for better NDT (faster, better sentencing, difficult contexts, more affordable)
- The need for validation, technology transfer and standards to support emerging techniques

The business case for investment in NDT responds to any or all of these drivers.

> *'Today's new material is tomorrows NDT problem - unless NDT is included in the development process'*

5.4 KEY ENABLING ACTIONS REQUIRED

Markets and business engagement (relating to the business case for broader use of NDT, linking NDT with wider plant life management capability, structural integrity, design etc).

- Prepare (advertise) case studies demonstrating successful use of NDT to secure business and sustainability benefits.
- Establish PR programme to promote benefits of increased use of NDT to businesses not currently engaged (seminars, business publications etc)
- Secure funding mechanism for demonstrator schemes to incentivise take up of new NDT technology, and also existing technology in new applications – covering technical feasibility AND business case.
- Establish programme to build closer links with the broader structural integrity community through professional bodies, businesses and networks.
- Engage insurance and regulatory sectors to encourage better use of NDT.

People (solving skill shortage, training, education, raising profile of NDT for recruitment etc)

- Establish programme to raise profile of NDT throughout education system, especially in relevant science & engineering degree and schools courses.
- Increase access to training provision to enable NDT professionals to improve skill levels and reskilling for new entrants.
- Facilitate schemes to increase recruitment of professional NDT personnel including apprenticeships, industrial placements, engineering doctorates.

Technology (around securing benefits from recently developed technology, tech transfer for emerging technology, actions related to funding, standards development etc)

- Extend RCNDE 5-10-20 year Vision to a wider community for establishing priority areas for technology development.
- Ensure NDT recognised as a key enabling technology by UK Government, EU and industrial research funding bodies (via KTNs, professional organisations etc).

- Secure and maintain funding routes for mid TRL technology development, validation and technology transfer. The Catapult initiatives provide an ideal platform for this work.
- Appoint custodian organisation for national library of validation samples.
- Develop plan to fast-track development of standards for new NDT techniques to enable rapid take up by end users and supply chain.

R&D (research to develop the new technology needed to meet the long term vision)

There is a need for a balanced and sustainable R&D programme if the employment and economic impacts from a successful NDT industry are to be secured in the medium and longer term. Based on inputs from key players in the sector and from leading academics the following areas are viewed as the current priority action areas related to R&D:

- Development of new inspection solutions to meet industry needs including faster and better sentencing techniques.
- Development of widely understood capability statements and recognised standards for emerging (UK) technologies
- Stimulate NDT R&D initiatives in applications where significant resource efficiency and sustainability benefits can be demonstrated.
- Maintain and consolidate a funded R&D network to enable active involvement of all key players including centres of expertise, universities, government, industry and finance (insurance).

6 CONCLUSIONS

NDT is an essential global engineering service that is used throughout the product lifecycle. Commercial success in many market sectors requires the deployment of effective inspection technologies by suitably qualified individuals.

As the engineering infrastructure ages and more complex systems are built, the need for ever more capable NDT methods will grow.

The UK NDT industry and R&D base has an enviable track record of significant achievement. It is well positioned and capable of delivering much more value to the UK economy and beyond if it can be cultivated with cross-sector investment aimed at addressing the three market opportunities of:

a) stimulating technology transfer for new inspection solutions

b) increasing business performance and growth

c) better recognition of the value of risk reduction through application of advanced NDT.

With continued investment in R&D and skills to further develop the capabilities and applications of the technology, future growth of key industry sectors will be underpinned.

Many of the UK companies in the sector are SMEs with technical excellence but limited resources, competing against mainstream global companies which have emerged following a period of consolidation in the industry. Value to the UK economy can be maximized if indigenous capabilities are brought to market and the wider industrial base is encouraged to invest in the best available technologies to realise the available benefits.

ANNEX 1

NDT IMPACT ON UK PRIORITY TECHNOLOGY AREAS AND HIGH VALUE MANUFACTURING COMPETENCIES

THE 8 'GREAT TECHNOLOGIES'

The UK Government Department of Business, Innovation & Skills has identified 8 'Great Technologies' which will propel the UK to future growth: big data, space, robotics and autonomous systems, synthetic biology, regenerative medicine, agri-science, advanced materials and energy. NDT will have important roles to play in at least 5 of these Great Technologies as noted below. It may also have an indirect role in the other areas such as inspection of the manufacturing facilities required for synthetic biology and agri-science products.

ENERGY

NDT impact: key role in both the manufacture and through-life management of new energy technologies and operational plants. NDT will be required at some stage for all energy technologies from manufacture of new energy storage devices to inspection of new high temperature fossil fuel power plants and new generation nuclear plant.

ADVANCED MATERIALS

NDT impact: New materials always generate new inspection requirement and challenges, and adoption of new materials requires suitable NDT techniques to enable quality assurance during manufacture and integrity assurance in-service. Examples range from aerospace composite materials to new additive manufacturing technology. Today's new materials are tomorrow's NDT problem!

ROBOTICS AND AUTONOMOUS SYSTEMS

NDT impact: the delivery of NDT technology to a much wider range of industrial applications will be enabled by advances in robotic and autonomous systems. Examples include inspection of deep water structures & pipelines, inspection in hazardous areas such as radioactive or remote locations. More advanced robotic systems will also enable more accurate, faster and cost effective inspection of complex components in high value manufacturing.

SPACE

NDT impact: key role in assuring the integrity of manufactured components and structures from launch spacecraft to satellite components, with new challenges related to the use of advanced materials and complex structures.

BIG DATA

NDT impact: As with advances in medical imaging, new NDT technology is now providing orders of magnitude more data than before with rapid growth expected in the future. The field can expect to benefit from techniques developed for other applications both for direct NDE data and for the increasing use of integrated asset management data covering entire plant and facilities which will in turn benefit the end-user industries. It has been shown that by extracting trends from historic data, the sensitivity of NDT can be increased by at least an order of magnitude.

HIGH VALUE MANUFACTURING – NATIONAL COMPETENCIES

NDT has an impact on all of the 22 identified competencies required for High Value Manufacturing. For HVM to become a long term value stream the four supporting legs of design, material, manufacturing and quality must all work together to produce an optimised, defect free part that will reliably achieve its design life, time and time again. This listing describes the impact NDT has on each of the identified competencies.

RESOURCE EFFICIENCY:

Securing UK manufacturing technologies against scarcity of energy and other resources

Energy generation, storage, management and security

Energy storage, energy management and transport focusing on energy cost, security and novel generation technology. New energy sources including next generation nuclear and energy transmission with low loss and low visual impact.

NDT impact: Defect detection capability has a major influence on the manufacturing methods and service intervals for all nuclear, fossil fuel and renewable plant.

Design and manufacture for sustainability and through-life

Design and manufacture of sustainable and innovative products including cleaner processes, low-carbon outcomes and less waste. Robust assembly for disassembly (recycling) and through-life engineering.

NDT impact: The minimum resource is used for a component if the design, material and quality (e.g. max flaw size) meet the design intent. NDT is the process used to ensure the parts are fit for purpose.

Design and manufacture for lightweight vehicles, structures and devices

Light-weighting to reduce energy consumption and emissions, reduce costs and increase efficiency. Composite, new and hybrid structures design, fabrication, joining and assembly. Multifunction component design and manufacture.

NDT impact: Hybrid structures are at risk of many more defect types, often novel and poorly understood. Specialised NDT methods are applied to ensure each element meets its quality standard. Without adequate NDT most manufacturers resort to sampling and cut-up analysis, with cost and safety consequences. Composite structures can be designed to much reduced weight (30%) through maximizing the fibre alignments and matrix properties. This is not done currently due to the inability to verify that the design intent has been achieved (±5° fibre alignment). NDT is being developed to achieve this level of imaging allowing a new opportunity of lean designs for complex composite structures.

Biotech, biological and synthetic biology processing

Alternative bio- and synthetic bio-based sources for new and existing products and processes. Processing of biologics for pharmaceutical and medical applications.

NDT impact: Medical groups are advanced on data processing and sentencing which is being sought to translate into industrial usage. Pharmaceutical processing uses extensive NDT for both plant and product.

MANUFACTURING SYSTEMS:

Increasing the global competitiveness of UK manufacturing technologies by creating more efficient and effective manufacturing systems

Process engineering capability across food, pharmaceuticals and chemicals

Development and application of common capability across food processing, pharmaceuticals and chemicals. Redesigning processes to increase yields and operational efficiency.

NDT Impact: NDT of processing plant is the main support to achieving safe and efficient operational performance. NDT of food, such as foreign body and contamination detection, package integrity and quality, is growing in significance as the supply chain complexity increases and customers expectations grow.

Design and manufacture for small-scale and miniaturisation

Miniaturisation, design and manufacture of smaller products such as specialised drugs, batteries and electronics. High precision and micro/nano-engineered products and processes and integration with macro-scale.

NDT impact: Regardless of scale defects can occur. NDT is a major contributor to achieving reliable electronics and mechanics by identifying processing anomalies and detecting defects.

Systems modelling and integrated design/simulation

Systems modeling and simulation tools, integrated system design, simulation and validation. Virtual prototyping, materials models, functionality and design. System integration of high-complexity products.

NDT impact: NDT models can now be used to demonstrate inspection capability at the design stage allowing for optimised design and manufacturing processes to be defined.

Automation, mechanisation and human/machine interface

Process automation and human/machine interface. Autonomy applications, particularly in production and servicing.

NDT impact: Currently NDT is normally performed as a separate manual inspection operation, making it slow and costly. A major opportunity for improvement is through automation with techniques becoming more adaptive and fast data analysis available for reliable detection. A clear route to de-risking the automation process would be through the Catapult Centres. The move to automation needs to be de-risked by using the Catapult Centres to demonstrate manufacturing capability. Regulators require trained inspectors to sentence indications that need 'Interpretation' so some element of skill will always be required. Advanced sentencing could use engineering models to analyse the effect of a defect with its known position size and shape.

Plug and play' manufacturing

Application of modularity to develop a high-volume production environment, where the production units can be combined in a flexible manner and serviced more effectively.

NDT impact: International NDT data standards (DICONDE) allow NDE systems to be integrated into manufacturing systems. Across the supply chain there is very poor interchangeability of data and equipment. Standard exchange formats will drive down the cost of inspection and improve uptake and thus safety.

Novel mechanical conversion processes for scale, economy and efficiency

The application of new primary and secondary mechanical conversion technologies and processes, for example, low-energy forming/forging, tool-less and one-shot manufacturing, new machine tool technologies and welding processes/applications including, for example, welding to titanium and magnesium.

NDT impact: Each manufacturing method introduces the risk of specific defect types and NDT must be armed to detect these as well as the pre-existing flaws the raw material may contain. The inability to demonstrate the structural integrity of a component can stop the uptake of a new manufacturing methods. These are currently live challenges for additive manufacture and composite materials.

Understanding, designing and manufacturing formulated products

Understanding design and manufacture of all formulated products for relevant sectors across the supply chain.

NDT impact: By employing NDT models at the design stage the defect detection capability of the design can be matched to the critical defect size for reliable operation. This also delivers the inspection methods and standards needed during manufacturing. Following this process avoids the common mistake of finding inspection is impossible after the design is fixed, resulting in part failures or low service lives. Monitoring and NDT technologies represent an opportunity for maintaining consistent product and processes for liquid and gel based manufacturing.

MATERIALS INTEGRATION:

Creating innovative products, through the integration of new materials, coatings and electronics with new manufacturing technologies

Smart, hybrid and multiple materials

Design, modelling and manufacturing processes of multi-metallic components and high-performance materials. Structures and components with integrated functions and tailored material properties and location-specific properties. Enhanced, faster joining capability with a range of materials.

NDT impact: Complex structures are susceptible to more defect types especially at interfaces, bonds and joints. NDT is the process by which the material, bond and joint quality and hence fitness for purpose are proven. NDT is a key enabler to allow these processes to be used.

Intelligent systems and embedded electronics

Robust 'live' data capture and comprehensive capture and use of product/process information. New sensor/non-destructive testing (NDT) devices and smart and multifunctional components which are embedded and/or intelligent. Large-area, printable, cheap electronics, integrated with other manufacturing processes for energy management, security, packaging and light-weighting. Integration of electronics into product and materials design.

NDT impact: By installing the NDT and CM sensors within the structure its health can be based on material degradation rather than using assumptions of always operating at maximum load. This also avoids costly interventions during the service lifetime.

Development and application of advanced coatings

Development and application of advanced coatings across multiple sectors.

NDT impact: Critical parameters of a successful coating include composition, thickness, diffusion depth, residual stress and adhesion. NDT process are available but these are often too slow or expensive. An opportunity exists to develop more suitable techniques as the use of coated structures grows. Detection of cracks under coatings is also being developed to avoid costly removal at overhaul.

MANUFACTURING PROCESSES:

Developing new, agile, more cost-effective manufacturing processes

Flexible, adaptive manufacture

Flexibility of production and manufacture supporting customised and rapidly reconfigurable manufacturing. Adaptive manufacturing including single-step, flexible reconfiguration and process technology that can adapt to feedstock of different types and compositions and mass customisation techniques.

NDT impact: The aim is not to increase the amount of NDT operations but drive the testing into the manufacturing process, so that it is less disruptive and that defects can be caught earlier. NDT is an integral part of a six sigma approach to manufacturing. Lean NDT delivers inspection requirements commensurate with the design context. Examples being extensive NDT for all jet engine discs and sample inspection for computer chips.

Combining product development steps in parallel/concurrent engineering

Real-time market analysis and response and systems to reduce development time. Combining marketing, design, manufacturing, standards, regulations and procurement and early user engagement.

NDT impact: NDT is the main process that regulators or insurers require to demonstrate the quality standards have been met. Driving NDT into the manufacturing process will ensure all defects are captured without an excessive inspection burden.

Additive manufacture

Application of layer manufacturing techniques or other freeform techniques for joining materials to fabricate intermediate and end-use products including direct digital manufacturing methods.

NDT impact: NDT is a key enabling technology and processes such as x-ray CT and laser ultrasound offer ideal methods to inspect these complex parts both dimensionally and for defects.

Net and near net shape manufacture

Initial production of items very close to the final net shape, reducing the need for surface finishing. Tool-less manufacturing with single actions to produce final parts or one toolset for full production system with one-pass production.

NDT impact: NDT is a key enabling technology. The near net processes can represent challenges for NDT but often benefit can be gained by using the NDT data for more than just defect detection, such as dimensional, structural and surface quality and material properties.

BUSINESS MODELS:

Building new business models to realise superior value system

Managing fragmented value chains to support HVM

Managing complex value delivery across the value chain in multiple locations and exploiting 'economies of small scale' to develop and produce close to the customer

NDT impact: NDT delivers value during manufacturing and through service life and can be performed by SME's through to large corporations. New technologies are providing better capability but the practical demands of inspecting, often remote, structures means very robust tools are required. Many small enterprises cannot risk the capital outlay for high cost systems (>£250k) unless they are confident of the business outcome. De-risking this step through Catapult projects could unblock the technology flow into smaller groups.

Building new business models to support HVM

New business models, with flexible arrangements to create new value

NDT impact: Integrating the NDT with the correct capability, will ensure components have the required quality and economic service life. This gives a predictable spares market and visible service business case. The current business models tend to place the highest risk on the first adopters of new technologies, and where this is a large company there is a danger of the technology being buried.

Developing and retaining skills to support HVM

Associated training and skills in HVM, provision of employees with cross-disciplinary skills and the ability to combine knowledge

NDT impact: The NDT industry has a strict training requirement for all its operatives. These are personal qualifications, adopted in the early 1980s, to ensure the required skills are available from a global workforce. The BINDT operate one such scheme which is 'Best in Class' and not only does this model have merit for any skill set, but the UK training and qualification industry represents a significant business sector to the NDT industry. The current demographic shows a skills shortage within a decade.

Managing risk and resilience to support HVM

Mechanisms to ensure HVM strategy and associated product strategies are inherently compliant with necessary standards across the value chain. Governance to ensure HVM product, service and process outcomes meet strategic intent.

NDT impact: NDT is often the main process used to demonstrate quality compliance.

LIST OF ABBREVIATIONS

NDT - Non-Destructive Testing; where structures are inspected for defects that would adversely affect their function.

NDE - Non-Destructive Evaluation; where parts are inspected to the highest standard possible to understand the flaws they contain. This is most often used in materials and process development programmes.

NDI - Non-Destructive Inspection; where NDT methods to make dimensional or property measurements.

BINDT - British Institute of Non-Destructive Testing (www.bindt.org)

CM - Condition Monitoring; methods usually using permanent sensors to monitor the health of a structure.

For the purposes of this report all of the above will be referred to as NDT.

EPSRC - Engineering and Physical Science Research Council (www.epsrc.ac.uk)

SME - Small to Medium Enterprise.

HVM - High Value Manufacturing.

HOIS - HOIS is the prime industry forum for discussing inspection issues and utilising improved inspection technology for applications in oil and gas. web-site at: http://www.hois2000.com

Materials KTN - Materials Knowledge Transfer Network

PCN - Personal Certification Scheme operated by BINDT to demonstrate an inspectors capability to perform an NDT inspection. Other schemes include CSWIP, controlled by TWI, ASNT controlled by the American Soc. for Non-destructive Testing and company based schemes controlled by EN471

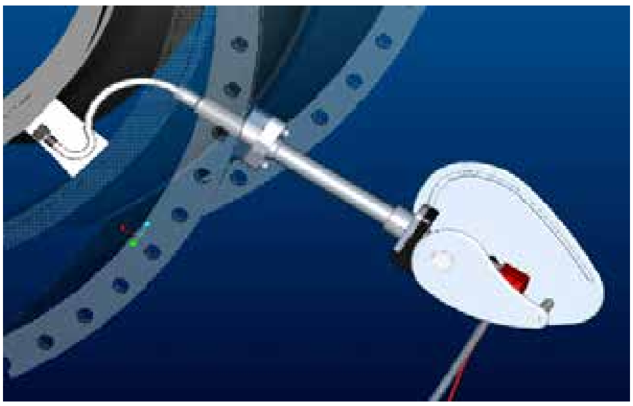
R&D - Research and Development

RCNDE - UK Research Centre in Non-Destructive Evaluation (www.rcnde.ac.uk)

TWI - The Welding Institute (www.theweldinginstitute.com/)

TRL - Technology Readiness Levels, definitions of the 9 readiness levels can be obtained from https://www.innovateuk.org/documents/1524978/2139688/High+Value+Manufacturing+Strategy+2012-15/ on page 13

X-RAY CT - X-ray Computer tomography, a 3D visulisation system using x-rays.



Above: Flexible NDT tooling for access to complex location, courtesy of Surgical Innovations

Right: Routine service inspection, using an ultrasonic array, being carried out on a Rolls-Royce aero engine

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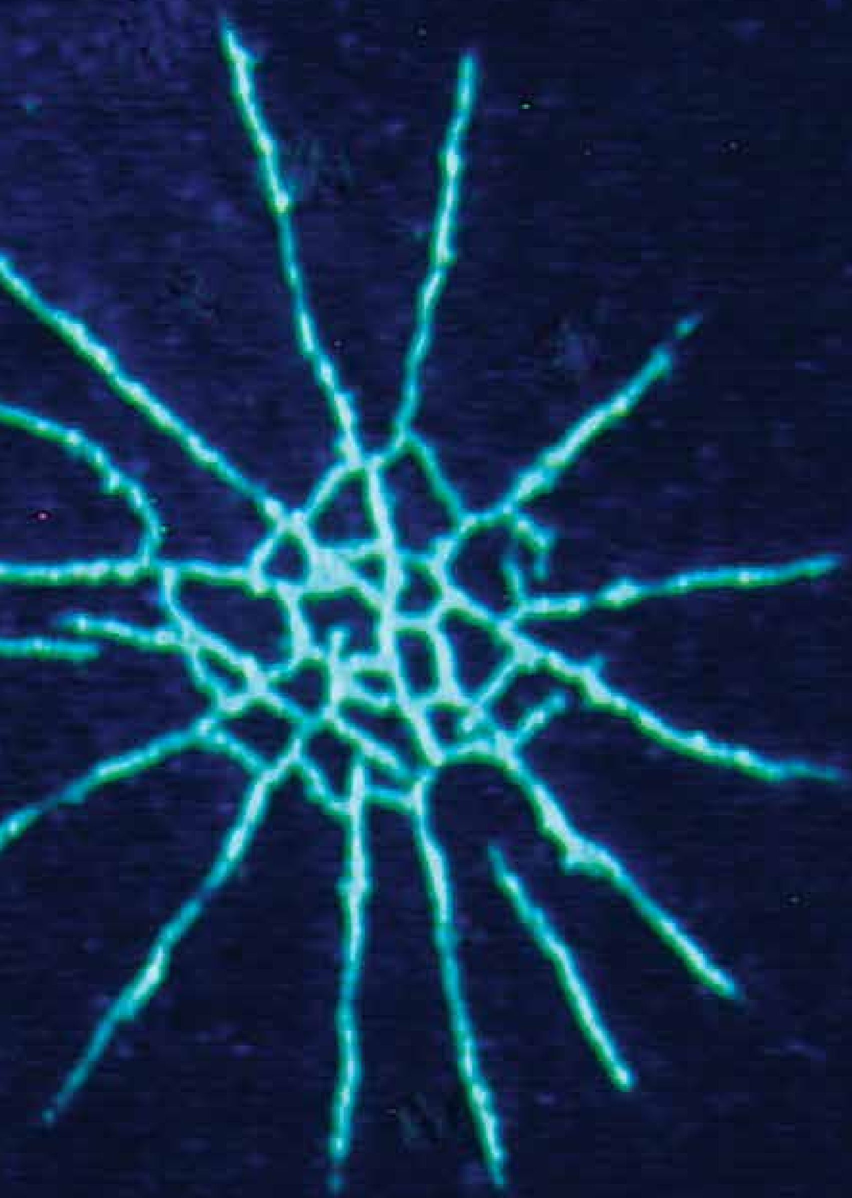

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