In-service inspection; training and certification aspects

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Abstract
A wide range of engineering plant is subject to periodic in-service inspection in order to ensure continuous, safe and cost-effective operation by using fracture mechanics and risk-based assessments. Non-destructive testing (NDT) is an integral part of this critical assessment process and as a result, the demand for reliable in-service NDT inspections in terms of detectability and sizing accuracy is continuously increasing. The most conventional degradation mechanisms such as corrosion, stress corrosion cracking, thermal or fatigue cracking differ significantly from manufacturing flaws; their detection, quantification and accurate sizing by NDT methods require different techniques, equipment and sensitivity settings. ISO 9712 specifies in-service inspection as one of the certification sectors; however, effectiveness of the NDT inspectors on utilising the required techniques and detecting the service-induced flaws is often debatable. In this work, the cause for this ineffectiveness is being identified by looking at the standard route to NDT certification according to ISO 9712. Focusing on how and at which level the necessary sector specific competencies are embedded in the training and examination processes the conclusion reached is that in-service inspection sector is not sufficiently covered. To address this problem many certification bodies have introduced sector specific training courses as endorsement courses to existing ones, consequently increasing the number of training hours. An alternative solution proposed in this work is the introduction of ISO 9712 compliant, employer specific schemes governed by accredited third party certification bodies in order to achieve the specific competence assurance requirements, which are related to in-service inspections.

Keywords: NDT, In-service inspection, NDT Training, Certification, ISO 9712

1. Introduction

In recent years, the unification of Non Destructive Testing (NDT) training and certification requirements under ISO 9712:2012 [1] has created a more harmonised approach to training and certification and it has made the third-party certification schemes the dominant route to certification worldwide. ISO 9712:2012 [1] specifies different certification sectors and most inspectors worldwide are certified either in single product sectors (e.g. welds) or in the industrial sector “pre and in-service inspection” (multi sector) following the training and certification process mandated by the standard. Consequently, inspectors working in different industries such as oil and gas, power generation, nuclear, automotive, motorsport, conducting manufacturing or in-service inspections are trained to the same competencies.

This work is focussing on the in-service inspection sector, which is becoming increasingly important for plant and asset life assessments and on the NDT methods mostly used in this sector. These methods include conventional and advanced ultrasonic techniques, such as phased arrays and ToFD, conventional and advanced radiography and electromagnetic NDT techniques, such as eddy current array and pulsed eddy currents.

2. The training and certification challenge

Certified inspectors in the “pre and in-service sector” are eligible to carry out inspections and assumed competent to detect, characterise and size both manufacturing and service induced flaws. However, their effectiveness on conducting in-service inspections is often debatable by industry. Training is an essential factor for NDT reliability as the main source of technical
knowledge and competencies. In addition, training also affects a number of other human factors, which have an impact on inspection performance. Therefore, training becomes part of the debate.

The training quality and the certification model are two factors affecting the qualification effectiveness and therefore the NDT reliability. Accredited third-party certification bodies, such as CSWIP NDT and BINDT for the UK, are responsible for governing the training and certification and maintaining the training quality. This work is focussing on the challenges that the training model for the in-service inspection sector is facing as well as proposing solutions to resolve the issues identified.

The key areas for research and the questions that need to be answered before attempting to suggest a solution to the challenge described are the following:

- What makes in-service inspection different?
- What competencies are required for those types of inspections?
- Is the training model one of the reasons for the ineffectiveness identified?
- Are all industrial sectors facing the same problem?
- How certain industries tackle the problem described?
- How the required competencies for in-service inspections differ from the ones provided by the standard ISO 9712 certification route?
- How these competencies can be mandated through the qualification process?

To answer these questions different approaches and research tools are used. Firstly, a critical review of the existing literature provides plenty of quantitative and qualitative data on NDT reliability and the effects of human and organisational factors on it. Secondly, in cooperation with key stakeholders an insight of in-service inspection procedures is available as well as information on how certain industries tackle the problem identified. Access to this information enables us to identify the key competencies required and the way to develop those competencies. Finally, the ISO 9712 route to in-service inspection certification is analysed and the competencies developed by this process are compared with the required competencies identified.

3. The In-Service Inspection characteristics

3.1 The importance of in-service inspection

The importance of in-service inspections has been identified many years ago and the nuclear industry is the leader in the field of research in NDT inspection reliability in this sector. The forward message in the work of S. R. Doctor et. al. [2] for the U.S. Nuclear Regulatory Commission (NRC) states that “the failure of in-service inspections to detect leaking cracks raised concerns regarding the effectiveness of ultrasonic testing being conducted at nuclear power plants and showed that improvements in inspection requirements were needed”. In response to poor performance, NRC conducted NDT reliability studies and the nuclear industry overall has invested years of research aiming at improving in-service inspection reliability.

In addition to the use of NDT methods for flaw detection, which is one of the main NDT scopes in any sector, in-service inspection results are extensively used in failure analysis (Astrom, Sinclair and Smalley) [3], in fracture mechanics (Doctor et al.) [4], in risk-based
inspection (RBI) and in fitness for service (FFS) assessment. The American Petroleum Institute (API) characteristically states that the availability of high quality UT data is often the cornerstone for FFS and RBI decisions [5]. The published work by the UK Health and Safety Executive (HSE) on plant ageing [6] also highlights the significance of NDT inspections in assessing plant integrity and affecting the decision making process for maintenance, life extension or decommissioning of ageing plants. In addition to reliable flaw detection, these assessments also require sizing accuracy, which becomes an integral part of in-service inspection reliability.

3.2 Nature of service induced flaws

It is widely accepted that flaw detectability and sizing accuracy depends on the flaw nature and the awareness of the flaw nature. The HSE: Best practice for the procurement and conduct of NDT-Part 1 [7] states that “The ultrasonic response of a defect and hence its detectability depends upon the defect characteristics. Shape, orientation, position, roughness, branching, length and through-wall size all affect the amplitude of the signal generated by a particular probe. If the inspection is not optimised for the detection of the defects of concern then the effectiveness of the inspection could be poor”.

Service induced flaws are significantly different from manufacturing flaws; therefore, awareness of the nature of the expected flaws is essential factor for reliable inspection. The testing procedure, equipment selection, sensitivity, sizing techniques, recording and acceptance levels as well as inspector’s competency to follow the procedure, identify the flaws and apply the right sizing techniques should all be optimised for the detection of the flaws of concern. Additionally, in regards to the comparison of manufacturing and in-service flaws the HSE: Best practice for the procurement and conduct of NDT-Part 1 [7, p.5] makes a clear statement that service-induced flaws impose additional requirements beyond those often included in manufacturing inspections.

Different industries, environments and products will develop different flaw types, however many plants share common types of defects. For example, nuclear reactors share common issues related to exposure to aggressive environments and operating conditions such as stress, irradiation, corrosive agents, vibration and fretting (IAEA) [8]. Stress corrosion cracking (SCC) is an example of service-induced flaw that is common in different industrial sectors and applications. According to HSE: Plant ageing [6], the nature of SCC is that it is branched in nature, making it difficult to detect, characterise and size with ultrasonics. A comprehensive list of the most important service-induced flaws is available in HSE: Plant ageing [6] and they are grouped in four main categories:

- Wall thinning
- Stress-driven damage, cracking and fracture
- Physical deformation
- Metallurgical / environmental damage

The same HSE report makes extensive reference to the required competencies as well as the training and certification requirements for NDT personnel and highlights the necessity of personnel competency [6, p.39].
3.3 NDT in-service inspection methods and techniques

In addition to the awareness of service-induced flaws and their characteristics, the NDT personnel conducting in-service inspections need different competencies in selecting the appropriate equipment, produce the appropriate test procedures (Level 3 personnel) and instructions, apply the appropriate sizing techniques and having in depth knowledge of the limitations of the technique applied on specific type of flaws.

In conventional surface NDT methods, the differences are usually limited to the selection of reporting levels and acceptance criteria. However, on volumetric methods such as ultrasonics and radiography the techniques used are significantly different. An insight of NDT procedures of a major nuclear generation organisation for the location and measurement of flow-accelerated corrosion (FAC) with ultrasonics as well as the weld inspection for in-service welds reveals that the sensitivity settings and the sizing techniques are much different from typical manufacturing applications. Inspection techniques might also be different. The tandem technique with ultrasonics, the use of Near Side Detection and Sizing Transducers – NSDS for SCC detection (Marr, Ginzel and Pennie) [9], the tangential radiography for detecting wall thinning and the pulsed eddy current method are all characteristic examples. Additionally, the technological advancements in Phased Array, ToFD and Eddy Current Array continuously generate new equipment and software and require special competencies by the inspector to use them effectively. Corrosion mapping, use of matrix probes, full matrix capture (FMC), two or three axis encoding, use of different scanners, analysis software, beam modelling and eddy current array (ECA) are also characteristic examples. Finally, various screening methods including traditional and non-traditional NDT techniques have emerged over recent years and they provide large areas screening of components for significant degradation. A comprehensive list of available screening techniques for in-service inspections as well as their capabilities and limitations are provided by the HSE study: Evaluation of the effectiveness of non-destructive testing screening methods for in-service inspection [10].

4. Training and certification aspects for the in-service inspection sector

4.1 The training and certification background

Over recent years, major steps have been taken for the harmonisation of personnel certification schemes worldwide and the unification of EN 473 and ISO 9712 standards under the latest ISO 9712:2012 [1] has been a milestone in that process. The third party certification schemes has become the dominant route to NDT certification worldwide. The published guide to qualification and certification of personnel for NDT by the International Committee for NDT- ICNDT [11] summarises the benefits of such schemes in the following four aspects:

- It complies with an internationally agreed ISO standard that is increasingly being adopted worldwide;
- It utilises an internationally developed training syllabus;
- Examinations (theory and practical) are provided directly by certification bodies or through authorised qualifying bodies and authorised examination centres under the control of certification bodies (many of which are linked to national NDT societies);
- It provides a harmonised standard for training, qualification and certification of NDT personnel and can be used as the base level for more specific employer-based or third party certification relevant to particular products or installations.
On the other hand employer based schemes such as SNT-TC-1A published by the American Society of Non Destructive Testing (ASNT) are also in use and mandated by the ASME code which is used worldwide, including regions in Europe. However, there are now amendments in the code allowing the use of national or international central certification programmes, to fulfil the examination requirements of the employer’s written practice, which must be in accordance with SNT-TC-1A or ANSI/ASNT CP189 [11]. Moreover, ASNT is also offering the ASNT Central Certification Program (ACCP), which is a third-party certification program and meets or exceeds the requirements of CP-106:2008, the U.S. adoption of ISO 9712:2005. The ASNT website [12] states that when the latest edition of CP-106 is published the ACCP will be revised to meet or exceed the requirements of the latest ISO 9712.

4.2 The ISO 9712:2012 route to certification

The international standard ISO 9712:2012 specifies requirements for the qualification and certification of personnel who perform industrial NDT [1]. A major element of this is the definition of certification sectors as specified in the normative Annex A of the standard. The sectors specified are product sectors and industrial sectors. Additionally, the standard specifies the minimum number and type of specimens for the Level 1 and Level 2 practical examinations [1, Annex B]. The sector specification and the minimum number of examination specimens for Level 2 certification examination, which is the majority of NDT certification worldwide, are summarized in Table 1. Industrial sectors such as metal manufacturing include all or a number of product sectors (multi-sector) and pre and in-service inspection sector includes manufacturing. The practical examination requirement for the pre and in-service inspection sector as mandated by the standard is three exam samples including castings or forgings and welds.

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<td>Composite materials (p)</td>
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Table 1
Sector specification and minimum number of exam specimens for Level 2 certification examinations according to ISO 9712:2012
Although the standard clearly states that the specification of product sectors does not preclude the development of additional sectors to satisfy national needs [1, Annex A], most accredited certification bodies follow this sector categorization in regards to the industrial sectors. It becomes apparent that there are no special examination requirements for the in-service inspection sector and the examination requirements satisfy the needs of metal manufacturing sector only.

Similarly, the training requirements and the syllabus specified for each method and sector by certification bodies are based on the technical report CEN ISO/TR 25107:2006 - Non-destructive testing — Guidelines for NDT training syllabuses [13]. According to these guidelines, for ultrasonic testing training the recommended number of hours for knowledge on various defects related to the manufacturing processes and service-induced defects related to the defined sectors is limited to 4 hours [13, par. 6.3]. In this limited time, candidates learn about all manufacturing defects in welds and potentially other sectors as well as service induced flaws. Additionally, the practical training on a generic course is based on specimens with natural or artificial manufacturing flaws for two main reasons. Firstly, the training needs to reflect the examination requirements and prepare the candidates for the examination, and secondly, service-induced flaws cannot be easily manufactured and access on specimens with those type of defects is restricted.

Interestingly, the code of conduct prepared by the British Institute of Non Destructive Testing (BINDT) for the Programme for the Assessment of Non-Destructive Testing in Industry (PANI 3 program) clearly states that “certification schemes, including PCN, are modelled on the detection of manufacturing defects and that the defects in the test samples are artificially induced and normally represent those brought about by the manufacturing process”. [14, Annex10, 2008].

Concluding, the issue identified is that the theoretical knowledge related to the nature and complexity of service induced flaws, as well as the practical competencies to detect, characterize and size these flaws are not mandated by the standard route to certification. Additionally, a great percentage of candidates participating in Level 1 or Level 2 courses have very little or no experience at all on the NDT method prior to the training course. Therefore, the courses, on the limited time available, are focusing on each method’s theoretical principles and on developing the basic competencies required for detection and sizing the main manufacturing flaws.

5. The response of industry to in-service inspection issues

5.1 Nuclear Industry – A different approach

The nuclear industry has identified the issue of NDT reliability for in-service inspection decades ago. The volume of published work is significant and includes quantitative and qualitative research studies, guidelines, probability of detection studies, case studies, human factors assessments, procedure assessments and studies of the impact of the organization on inspector’s performance. D’Agostino, et al. [15] on the literature review of published work with key words including NDT, training, human factors or ultrasonics, states that 50 out of 91 relevant references were specific to the nuclear industry, 14 references were related to aviation or aerospace, only 1 came from the offshore oil industry and 26 were not specific to a
single industry. The driver for this research programs and the associated investment is the fact that reliable in-service inspection is significantly critical for the nuclear industry.

Training is one of the important factors taken into account and studied in most of the published literature. It is assumed that more training or experience is highly beneficial to the reliability of NDT inspections. However, numerous studies have shown that the quantity of training and experience is not necessarily related to better inspection performance. The work of T.T Taylor et al. [16] on the evaluation of human reliability in ultrasonic in-service inspection for the nuclear industry concludes that NDT certification levels are not related to UT in-service inspection ability and that one of the least valuable aspects of the special training the inspectors received for the purpose of the program was the classroom training. On the other hand, the most valuable aspects of training were practice on specimens with actual cracks and comparing techniques with other personnel. Most research works in the nuclear industry have demonstrated similar results and it becomes evident that it is the training model, which is of great significance rather than the quantity or the certification level.

In response to these results, the nuclear industry has adopted a different approach to NDT training. Although NDT inspectors are being certified mostly through third-party certification schemes, the nuclear industry invests heavily on additional training which is procedure driven and focused on the in-service inspections sector for detecting SCC or other relative to the industry service induced flaws. The International Atomic Energy Agency (IAEA) has published training guidelines [17] and the Electric Power Research Institute (EPRI) has also published guidelines recommending procedure training of contractors that addresses the examination scope, the specific NDT procedures, equipment, and software that are to be used. As a result, the nuclear industry runs in-house procedure driven training programs for its personnel and for contractors involved in NDT inspections. Those programs include awareness of the nature of sector specific flaws, practical training on real life inspection environment, the use of specimens with real service induced flaws, critical sizing and training on specific inspection techniques and equipment. The extend of those programs, as told by stakeholders, exceeds 10 weeks in duration annually. Additionally, more research has been carried out on the human, procedural and organisational factors affecting NDT reliability.

5.2 Other industrial sectors

Aerospace sector is also an industrial sector that tackles in-service inspections effectively. However, the aerospace sector is defined as different industrial sector in ISO 9712:2012 and the approach to NDT certification is generally different and outside the scope of this work. What both nuclear and aerospace industries have in common is the fact that they are both quality driven rather than cost driven.

All other, cost driven industries included in the “pre and in-service inspection” sector are lagging behind in tackling the issue identified. The studies on reliable in-service inspection in other industries is very limited and relatively recent. The UK’s HSE initiated and sponsored the Programme for the Assessment of NDT in Industry (PANI) starting in 1997 and running through to 2007. The impetus for the work came out of a desire to assess the effectiveness of NDT as applied outside of the nuclear industry in the UK. All three PANI projects were focussed on manual ultrasonics; however, B. McGrath et al [18] on their work reviewing the PANI projects state that there are many lessons, which can be successfully transferred over to other NDT techniques. Unfortunately, the results of the PANI projects and the guidelines
documents issued by the UK’s HSE are not widely known and very few NDT organisations have made changes in respond to the issues identified, resulting in general lack of awareness.

6. The human factor in NDT reliability

The recent work of D’Agostino, et al. [15] for the U.S. Nuclear Regulatory Commission (NRC) summarises the published literature related to human factors affecting NDT reliability and states that variations in NDE reliability cannot be attributed to a single “human factor”. Instead, it is likely that many factors interact with each other in a sociotechnical system to collectively impact NDE performance (Carter & McGrath, 2013; Enkvist, Edland, & Svenson, 1999; Norros, 1998 cited in D’Agostino et al. [15, p.7].

D’Agostino et al. [15] adopts the human factors categorization scheme based on Neville Moray’s sociotechnical systems model. The five categories are: task characteristics, individual differences, team or group characteristics, the physical environment, and organizational factors. Although the role of training is primarily to provide the technical knowledge and competencies to carry out the inspection tasks, it is also involved in most of the five human factor categories.

In regards to task characteristics, training is affecting the pre-job preparation, the inspector’s resources and the process factors. Training also has an impact in cognitive factors, specifically in memory and perception. An inspector looks for familiar patterns in the material and compares them to previously seen patterns from either previous experience or training using a combination of both long term and working memory processes (Enkvist et al., 1999, cited in D’Agostino et al. [15, p.23]. Additionally, stress and workload, expertise, level of confidence, psychological factors, performance within a team and environmental factors all have an impact on inspection performance and they are all related to training, directly or indirectly. Finally, training strategies imposed by the organisation heavily affect the inspection performance. “Hands on” training with immediate feedback is most likely to improve performance (Spanner et al.) [19]. The HSE PANI projects are also highlighting the impact of training on human factors in regards to NDT reliability.

7. Proposed solution

7.1 Respond of training organisations and certification bodies

NDT certification bodies as well as training organizations have identified the issue and in respond, they have developed application specific courses related to in-service inspections. API offers Qualification of Ultrasonic Crack Sizing Examiners that use conventional ultrasonic and Phased Array methods (QUSE and QUSE-PA). CSWIP NDT and BINDT also offer critical sizing certification courses as well as corrosion detection and mapping certification courses for phased array and conventional ultrasonics. Although, those courses can potentially enhance NDT in-service reliability they are being offered as endorsement courses to existing certificate holders resulting in cumulatively very long training durations. Given the fact that there are no shortcuts when it comes to NDT training and inspection reliability, this seems the only course of action by following this training and certification model. However, cost driven industrial sectors are reluctant to invest in long duration training especially when this type of certification is not mandated by manufacturing or in-service inspection specifications.
A different approach would be to change the training model rather than adding training courses to achieve specific competencies. ICNDT has attempted to offer an alternative to the training model by introducing performance based qualification with the introduction of ISO TS 11774 [20]. The qualification methodology described by ISO TS 11774 is based upon the candidate’s ability to demonstrate capability in detecting and sizing critical discontinuities equivalent to those to be detected and sized only after the NDT procedure has been qualified [11]. The European Federation of NDT (EFNDT) in its guidelines for NDT quality system [21] summarises the disadvantages of the latter and is highlighting the fact that there is a clear overlap in scope with ISO 9712 and that there are difficulties for recognition and mutual agreement between different sector’s committees. Besides, ISO TS 11774 has still the status of a technical specification and according to the ISO regulations, on the next review it will be either transformed into an ISO standard or withdrawn.

7.2 The third-party employer specific scheme

The proposed solution in this work is also offering an alternative to the certification model by combining the employer based certification schemes and third party certification. The third-party employer specific scheme proposed is based on the principles of ISO 9712, is governed by an accredited certification body but includes involvement of industry. This model is introducing employer specific inspection requirements in addition to the standard CEN ISO/TR 25107 training requirements in one training course tailored to meet the needs of specific industries. In effect, it bridges the SNT-TC-1A and the ISO 9712 models by offering the best of both worlds.

Such a model could meet the reliable inspection characteristics in regards to training as identified by the PANI projects, such as job specific training, covering the background, equipment and procedure and defect specification [14]. It could also enhance NDT reliability regarding the effect on human factors, especially if specific material characteristics, environmental factors and development of confidence levels are introduced into the training and finally meet the requirements of cost driven industries for not extensively long, competency based training courses.

On the practical side, those schemes would start by the standard training syllabus mandated by ISO 9712 and an employer’s written practice based on the principles of SNT-TC-1A schemes. The written practice may include specific techniques, materials under test, sizing and reporting requirements, specific equipment, sensitivity levels or an entire procedure. The written practice may also include a training format such as working in groups or even mandate working in a specific environment.

7.3 Challenges

This model suggests joint efforts by all involved parties. This introduces challenges that need to be addressed. The challenge for industry is that it needs to be more involved in the training and certification process by providing access to materials, flawed samples, procedures, equipment and facilities as well as investing time in producing realistic written practices meeting the inspection requirements. Challenges are also introduced for the training organizations and certification bodies. They need to significantly increase their flexibility for responding to the employer specific training requirements. Trainers should be able to adopt their training style, be aware of different techniques and be dexterous with a large range of
different equipment and software. Certification bodies in cooperation with the training organizations also need to become more flexible and extend the scope of their activities.

The third-party employer specific scheme proposed in this work is the respond to mitigate the issues identified for the in-service inspection industrial sector. However, the proposed training model could be used as an alternative to the standard ISO 9712 route to certification for any industrial sector. Flexibility and adoption to change are characteristics than can only be beneficial to the process. Finally, the technological advancements and the introduction of new advanced techniques with their significant range of associated equipment and software, require a new approach to the training and certification model including inherent flexibility.

8. Conclusions

The purpose of this work was to investigate the debate over the ineffectiveness of certified inspectors performing in-service inspections. At first, the in-service inspection characteristics and competencies required are identified by investigating the research programs on NDT reliability conducted mainly by the nuclear industry and the UK HSE. In-service inspection characteristics are found to be significantly different from manufacturing inspections in regards to flaw awareness and NDT techniques utilised. Then, the standard route to training and certification according to ISO 9712 is analysed and the competencies developed by this process are compared with the competencies required for in-service inspections. It is evident that this training and certification model is focussed on detection and sizing of manufacturing flaws and no additional training and examination requirements are mandated for the in-service inspection sector. Industry has identified the problem but it is only the nuclear sector that resolves it effectively. The best practices used by the nuclear industry are investigated and the reasons that other industrial sectors are lagging behind in tackling the problem are identified. Finally, a new qualification model is proposed, the third-party employer specific scheme, which combines elements from employer-based schemes and the ISO 9712 third-party certification. This model requires joint efforts by industry, training organisations and certification bodies and its successful implementation relies on addressing the challenges highlighted.

References


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