Programme for the assessment of NDT in industry

PANI 3

Prepared by Serco Assurance
for the Health and Safety Executive 2008
This report describes the work undertaken and the results obtained during the 3rd project under Health and Safety Executive’s Programme for the Assessment of NDT in Industry (PANI 3). The project was instigated with the objective of identifying solutions which will allow industry to optimise performance and minimise the magnitude of operator variation in the application of manual ultrasonic inspections. The PANI 3 project was managed on behalf of the Health and Safety Executive by Serco’s Inspection Validation Centre (IVC). In order to keep the report easy to read and assimilate, the main text gives the key information and the reader is referred to the Appendices for the supporting detail.

The project comprised of an investigation into the human factors aspects of the manual ultrasonic task and an assessment of the organisation of NDT and the NDT process (initially referred to as QA Assessment). Following a data gathering exercise which is reported in Appendix 2, experimental work was performed with the twin objectives of investigating the operators’ decision making processes and the correlation of ultrasonic performance with the operators’ scores on ability tests and a number of personality scales.

The assessment of the organisation of NDT was conducted through eliciting information from operators and NDT vendor companies and reviews of previous reliability studies and other initiatives to improve NDT reliability.

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Executive Summary

This report describes the work undertaken and the results obtained during the 3rd project under Health & Safety Executive’s Programme for the Assessment of NDT in Industry (PANI 3). The project was instigated with the objective of identifying solutions which will allow industry to optimise performance and minimise the magnitude of operator variation in the application of manual ultrasonic inspections. The PANI 3 project was managed on behalf of the Health & Safety Executive by Serco’s Inspection Validation Centre (IVC). In order to keep the report easy to read and assimilate, the main text gives the key information and the reader is referred to the Appendices for the supporting detail.

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The assessment of the organisation of NDT was conducted through eliciting information from operators and NDT vendor companies and reviews of previous reliability studies and other initiatives to improve NDT reliability.

The conclusions derived from the work are as follows:

1. The PANI 3 data revealed that operator performance on the test pieces was related to their scores on one of the ability measures and two of the personality scales measured in the project. Better operators’ performance was associated with higher scores on the test of Mechanical Comprehension and lower scores on the personality scales measuring Original Thinking and Cautiousness. The relationship between these ability and personality measures, and ultrasonic inspection performance, was stronger than that found between ultrasonic inspection performance and the number of years of experience that an operator had in undertaking manual ultrasonic inspections.

2. The PANI 3 test pieces were challenging but the ultrasonic results obtained from the 40 operators who participated were similar to those observed in previous PANI and other round robin exercises:
   • All defects in the test pieces used in PANI 3 were detectable using the applied procedure.
   • All defects were detected by at least 40% of the operators who inspected for them.
   • Average detection frequencies for each test piece varied from 58% to 67%.
   • The average circumferential positioning error over all defects for each operator ranged from 0mm to 28mm.
   • The average length error was +1.3mm and the average standard deviation for operators reporting two or more defects was 12mm. The external circumference of all three test pieces was 688mm.
   • The number of false calls overall was 16 with 2 operators reporting 2 and no operators reporting a higher number.

3. In a theoretical examination, the operators in PANI 3 demonstrated a good understanding of the basic principles of ultrasonic inspection as used every time an inspection is done. Their comprehension and knowledge of important but less frequently used features of ultrasonic inspection was less good.
4. De-briefing the operators following their inspection of the test pieces revealed a number of important conclusions based on discriminating between closely located defect and geometric echoes:

- The operators were easily able to describe why they had determined that certain signals were from geometrical features of the test piece rather than defects.
- The operators were less able to explain why they had reported indications as arising from defects. Knowledge of how ultrasonics interacts with defects was not used to assist the decision-making process in many cases. Their reasoning processes were not well defined and they frequently came to a decision before all relevant information had been acquired.

5. Observation of the trials and analysis of video recordings highlighted that for the best performance, operators should be able to:

- Understand the implications of the geometry for the inspection. This requires that operators be given training in the understanding of ultrasound / reflector interaction.
- Apply the procedure in a systematic way. This requires that the procedure needs to be written in a way which specifies the decision making steps.

It is worth noting that current certification arrangements are not dependent on operators being able to correctly characterise defects.

6. The output from the operator’s workshop showed that an operator’s ideal inspection process is one where:

- The preparation for the inspection in terms of access, safety and plant surface condition is performed by the client or NDT organisation, as appropriate, in advance.
- Suitable documentation including risk assessments, inspection procedures, standards, acceptance standards, access and cleaning requirements, drawings and photos and equipment inventory are provided.
- Adequate time is allowed for the inspection.

This allows the operator to concentrate simply on carrying out the inspection. The NDT organisation should ensure that the operator is aware of the extent of his responsibilities.

7. Feedback from contributors to the project indicated that an organisational culture can predominate in which inspection is regarded simply as a statutory or contractual necessity rather than as a valuable process which can help avoid plant failures. This can lead to problems with lack of information, inadequate preparation, poor access and working conditions, unreasonable time pressures and poor remuneration. Also, operators are aware of, and influenced by, the pressure to report a clean bill of health considering the costs and time delays to the operation of plant if a defect is found.

These conclusions lead to the following recommendations from the project:

1. NDT organisations and operators should consider the use of ability and personality tests for:

- Selecting new trainee ultrasonic operators.
- Tailoring training courses to meet individual’s specific needs for development.
- Developing procedures at a suitable level of detail to support operators when undertaking assessments.
- Identifying skills that should be developed as part of ultrasonic operator initial and refresher training.

2. Where relevant to an operator’s role, his/her training should be expanded to include:

- A better understanding of how ultrasound interacts with defects and how to use this knowledge.
- A knowledge of how observed ultrasonic signals arise from different potential sources of reflection and how to make a characterisation decision based on this information.
- A grounding in the preparation requirements regarding administration, documentation, equipment and site support needed as a basis for a successful inspection. These requirements must be met prior to going to site to carry out the work.
- A clear awareness of the roles and responsibilities in the inspection process.
3. Inspection procedures should be written in a way which promotes their systematic application.

4. Apart from carrying out the inspection itself, the role of operators in an inspection should be limited to verifying the adequacy of the arrangements for safety, access and plant condition. The preparation for the inspection and the provision of an adequate and appropriate inspection procedure is the responsibility of the client and/or NDT organisation as appropriate.

5. All organisations should promote a culture in which NDT is valued as a key input to the safe and cost-effective operation of plant. Organisations must provide or facilitate the necessary preparation of and on-site facilities for inspection and in particular they must allow adequate time for the inspection to be completed safely, accurately and reliably. A Code of Conduct for Industrial Plant Owners has been proposed to assist in this process (see Appendix 10).
Contents

1 Introduction 7

2 Project Scope 7
   2.1 Human Factors 7
   2.2 Quality Assurance (QA) 7
   2.3 Management Committee 7

3 Work Programme 8
   3.1 Data Gathering 8
   3.2 Experimental Work 8
   3.3 Analysis 8

4 Experimental Work 8
   4.1 Ability Tests 9
   4.2 Ultrasonic Test Piece Details 11
   4.3 Ultrasonic Inspection 13

5 Aptitude Test Correlations 13
   5.1 Analysis Procedure 13
   5.2 Comparison with General Population 14
   5.3 Correlation with Ultrasonic Performance 15
   5.4 Conclusions 17

6 Ultrasonic Results 17
   6.1 Operator Performance - Detection 17
   6.2 Operator Performance – False Calls 19
   6.3 Operator Performance – Positioning & Length Sizing 19
   6.4 Defect Detectability 21
   6.5 Summary 21

7 Theoretical Questions 22
   7.1 Analysis of Results 22
   7.2 Summary 24

8 De-brief and Observations 24
   8.1 Methodology 24
   8.2 Results 25
   8.3 Summary of Decision Making Analysis 27
   8.4 Decision Making in Detection and Characterisation 27
   8.5 Overall Observations Regarding the Inspections 28
8.6 Procedure Improvements
8.7 Procedure Writing – Human Factors Considerations

9 NDT Organisation – Analysis of Current Practice
9.1 Review of Workshop Results
9.2 Process Risks
9.3 Job Descriptions

10 Proposed Solutions
10.1 Safety Culture
10.2 Recommendations from Previously Reported Studies
10.3 Experience from the USA
10.4 Industry Examples of Current Good Practice
10.5 Other Ideas
10.6 Summary

11 Conclusions

12 Recommendations

13 References

Appendices

Appendix 1 PAN 3 Management Committee
Appendix 2 PANI 3 Interim Report
Appendix 3 Operator Details Form
Appendix 4 PANI 3 Test Pieces
Appendix 5 Ultrasonic Procedure Used For PANI 3 Inspections
Appendix 6 Analysis of Test Data
Appendix 7 PANI 3 Defect Results
Appendix 8 PANI 3 Theoretical Questions
Appendix 9 Proposed Procedure Format
Appendix 10 Proposed Code of Conduct
1 Introduction

The first project in the Programme for the Assessment of NDT in Industry (PANI) identified potential shortcomings in the application of manual ultrasonics [Ref. 1]. PANI 2 quantified the benefits that would be gained from addressing these shortcomings by adopting an inspection specific procedure or job specific operator training [Ref. 2]. However, PANI 2 highlighted that the variation in performance between operators has an overriding impact on inspection results, greatly in excess of any benefits arising from improved procedures or training.

As a consequence, the PANI 3 project was instigated with the objective of identifying solutions which will allow industry to optimise performance and minimise the magnitude of this operator variation. This report describes the work undertaken and the results obtained during the PANI 3 project.

The PANI 3 project was managed on behalf of the Health & Safety Executive by Serco’s Inspection Validation Centre (IVC).

In order to keep the report easy to read and assimilate, the main text gives the key information and the reader is referred to the Appendices for the supporting detail.

2 Project Scope

The challenge presented by the results of the PANI 2 project was how to reduce the magnitude of the variation in performance of nominally similar operators. Discussions centred on the skill and attitude of the operator and it was evident that a human factors investigation was required to identify areas for improvement. However, whilst the operator is important, he or she does not work in isolation from others involved in the NDT process through responsible positions in the client and NDT organisations. Therefore, it was also deemed necessary to assess the NDT process as a whole to see if potential improvements lie in this area.

2.1 Human Factors

A number of attendees at the PANI 2 results seminar stated that they knew who their best operators were. This raised the question of what criteria were used to identify the best operators and whether these criteria were valid. Although the personal characteristics of operators appeared to offer a useful area for investigation, the advice from human factors specialists at the time was to concentrate on the skills required for the manual ultrasonic task which can be developed rather than on the personality traits which are more difficult to modify. The human factors study was therefore targeted at this area.

2.2 Quality Assurance (QA)

Often the best way to identify improvements in a task or process is to ask the people directly involved in the day to day application of the task or process. The scope of the QA assessment was to establish current practices and through input from both operators and NDT vendor companies, to identify improvements to the NDT process which would result in improved operator performance. Although this activity started out as an assessment of what is usually termed QA it expanded in scope during the project to cover the whole infrastructure and NDT organisation. At the results seminar this activity was entitled “The Organisation of NDT”.

2.3 Management Committee

The use of a broadly-based Management Committee to oversee this type of project had proved its worth in the previous two PANI projects and so was continued in the current project. Formal terms of reference for the committee were produced. The membership of the committee and the terms of reference are given in Appendix 1.
3 Work Programme

The work programme consisted of three major activities.

3.1 Data Gathering

There have been many previous studies into NDT reliability and, in order to maximise the benefits of the current work, it was important to build on this existing knowledge. A literature review was undertaken on NDT reliability and human factors. A visit was made to an NDT training school and to an operational NDT unit. Also, an operator workshop was held to elicit information on current and ideal NDT processes. Details on this data gathering exercise and the rationale behind the subsequent experimental work is reported in the PANI 3 Interim Report given in Appendix 2.

3.2 Experimental Work

The experimental work was targeted at collecting new data on the human factors aspect of operator performance although, as discussed below, it does overlap with the QA work. Operators were required to inspect one of three test pieces containing realistic defects and their performance was analysed. The operators also completed a number of ability tests and a personality test and the results of these tests were correlated with the ultrasonic performance. Full details are given in Section 4.

During this stage of the project, the QA assessment work was progressed by gathering data from NDT vendor companies. This is reported in Section 9 below.

3.3 Analysis

The data amassed during the data collection and experimental phases was then sorted and analysed. The results were then examined with the objective of identifying potential solutions which would improve future consistency in performance between operators. The analysis is described in Sections 5 to 9 with the proposed solutions described in Section 10.

4 Experimental Work

As described in the Interim Report (Appendix 2), the experimental work had two objectives:

1. To establish if there is any correlation between an operator’s performance in selected ability tests with the ultrasonic performance on test pieces.
2. To investigate the decision making processes of operators once they have observed an ultrasonic signal on the flaw detector screen.

To achieve both objectives, 40 operators attended Serco Assurance’s Inspection Validation Centre at Risley. A maximum of 2 operators attended on any one day and the timetable of activities was as follows:

09.00 to 13.00 approx. Undertake Ability Tests under the supervision of psychologists from the Division of Psychology and Social Change, Manchester Metropolitan University

Lunch break

14.00 to 17.00 Manual Ultrasonic Inspection of 1 Test Piece. The inspection of the test pieces was filmed using two cameras directed at each operator. The information was recorded on a hard disc CCTV
On completion of the inspection, the operators were de-briefed in order to gain insight into their decision making processes. This took approximately 30 to 45 minutes. Relevant CCTV recordings have been reviewed as part of the de-brief analysis. Details of the de-brief are given in Section 8.

The operators provided information on training, qualifications and experience on the operator’s details form (See Appendix 3) and were asked to provide narrative answers to two theoretical questions on ultrasonic inspection and associated QA. The purpose of the latter was to gather more information regarding operator knowledge of the manual ultrasonic inspection task. The operators were given 30 minutes to complete the questions which allowed the start and hence finish of the inspection to be staggered when two operators were in attendance. Details on the questions are given in Section 7.

The operators finished at some time between 18.00 and 19.00, making it a long and intensive day.

The operators were hired from a number of NDT vendor organisations which varied in size, industry sector and geographic location. Although the test piece represented a T-joint geometry, it was deemed beneficial to the experiment to hire a number of operators who had PCN Level 2 manual ultrasonic qualification in Plate & Pipe only. These operators would provide information on the application of basic ultrasonic knowledge and skills and on the ability of operators to adjust to different situations.

### 4.1 Ability Tests

As described in the Interim Report (Appendix 2) a series of six mechanical ability tests were identified as suitable for the experiment. If a correlation between results from these tests and ultrasonic performance could be determined, then the tests could be used to identify skill areas for individual operators to enhance in order to improve performance. In addition, the tests could be used as part of the selection process for operators.

The individual tests which the operators completed were as follows:

- **Following Instructions (VTS1)** measures the ability to understand written instructions (in a technical context).
- **Numerical Estimation (NTS2)** measures the ability to estimate quickly the answers to numerical calculations.
- **Mechanical Comprehension (MTS3)** measures the understanding of basic mechanical principles.
- **Fault Finding (FTS4)** measures the ability to locate faults in a complex system.
- **Spatial Checking (STS5)** measures the ability to locate differences between complex designs rotated or reversed in two or three dimensions.
- **Diagrammatic Thinking (DTS6)** measures the ability to follow a symbol through a flow chart given a sequence of pre-defined instructions.

Details on each test can be obtained from the publisher’s website [Ref. 3] and a review of the tests can be obtained from the British Psychological Society’s website [Ref. 4].
Despite the initial reservations about the assessment of personal characteristics, described in Section 2.1 above, the literature review (See Appendix 2) identified that personality traits had the potential to strongly influence an operator’s performance. So the operators also completed the Gordon Personal Profile Inventory (GPP-I), published by ASE [Ref. 5]. Again a review of the test can be obtained from the British Psychological Society’s website [Ref. 4].

The GPP-I measures eight personality traits:

- **Ascendancy (or self-assuredness)**: the degree to which an individual adopts an active role in the group, makes independent decisions and is self-assured in relationships with others.
- **Responsibility**: the degree to which an individual sticks to the job assigned to them, is persevering and determined and can be relied upon.
- **Emotional Stability**: the degree to which an individual is free from worry, anxieties and nervous tension.
- **Sociability**: the degree to which individuals like to be with and work with people.
- **Cautiousness**: the degree to which an individual considers matters before making a decision, takes chances or runs risks.
- **Original Thinking**: the degree to which an individual tends to be intellectually curious or the extent to which they dislike working on difficult or complicated problems.
- **Personal Relations**: the degree to which an individual has trust in people and is tolerant, patient and understanding.
- **Vigour**: higher scores indicate vigour, energy and the ability to accomplish more than the average person.

The sum of the scores of the first four traits, i.e. Ascendancy, Responsibility, Emotional Stability and Sociability, provides the composite score for an overall measure of self-esteem.

NOTE:
In order to derive benefits from the results of the Gordon Personal Profile Inventory, it is important to note two points:

1. **Traits are characteristics which people are predisposed to apply in any given situation.** However, this does not mean that people are constrained to behave in a manner determined by their traits: often they will behave in a manner determined by the actual situation rather than their trait. What is important is that individuals and managers are aware of individual traits so that they can ensure that any decision is based upon the requirements of the situation and is not inappropriately influenced by a particular trait.

2. **There is no right or wrong score for any trait.** The intrinsic value of the particular score and hence trait will vary depending on the situation the operator is confronted with. Often both a very high and a very low score can be a disadvantage in a particular task.
4.2 Ultrasonic Test Piece Details

The design of the ultrasonic test pieces was pivotal to the success of the project. The following requirements had to be satisfied:

1. Data from a relatively large number of operators had to be collected in order to provide statistically valid results and conclusions. In the ideal experiment all operators would have inspected the same test piece. Hence the number of test pieces had to be kept to a minimum.

2. The test pieces had to be able to test the decision making process of the operators so they needed to contain a variety of defect responses and also geometric reflectors.

3. The reports generated by the inspections had to generate performance data for comparison with the ability test results. Hence, the test pieces needed to be challenging so that a range of results would be produced.

4. The security of the test piece information had to be maintained over the extended period of the experimental work so it was necessary to be able to interchange test pieces as required.

5. There had to be sufficient test pieces to allow the testing of more than one operator at any one time in order to maximise the number of operators who could be tested within the budget.

The test pieces which met the above requirements were based on the following:

a) A T-joint cross section, as shown in Figure 1, containing an un-fused land similar to the PANI 2 test piece which had been shown to be challenging with a variety of geometric echoes.

b) Unlike the PANI 2 T-joint test piece which was a linear weld, the PANI 3 test pieces were manufactured in a circular geometry, as shown in Figure 2. This allowed the flexibility of giving operators a different circumferential start position hence minimising the possibility of details of a defect at a fixed circumferential position being passed among the operator community.

c) A minimum of two test pieces were required to deliver the final timetable of two operators attending at any one time and so three test pieces with identical external appearance were manufactured. This number, coupled with the flexibility of the circular design, gave confidence in the security of the defect information.
Each test piece had a unique identification number:
P3 – PANI 3
TP – Test piece
0X – X being the number of the test piece: 1, 2 or 3.

The numbers of defects implanted in each test piece were:
P3TP01 – 2 defects
P3TP02 – 3 defects
P3TP03 – 4 defects

Full details of the three test pieces used in the experimental work and the defects they contained are given in Appendix 4.
4.3 Ultrasonic Inspection

Each operator was assigned one of the three test pieces to inspect. As described in the previous section, the test pieces were of identical geometry and contained similar defects with only the number of defects varying. Hence they presented a similar challenge to the operators. The final numbers inspecting each test piece were:

- P3TP01 – 12 operators
- P3TP02 – 13 operators
- P3TP03 – 15 operators

The Inspection Validation Centre (IVC) provided the ultrasonic probes, leads, couplant and test blocks for use in the inspection. The majority of operators used their own flaw detectors, although a few used flaw detectors provided by the IVC. All the operators applied the same ultrasonic procedure which is given in Appendix 5. However, due to the requirement to complete the work within the limited time, steps were taken to allow the operators to concentrate on the actual inspection of the test piece. These were:

1. Calibration details for the probes were provided to the operators to minimise the preparation time.
2. Sheets showing a scale cross sectional drawing of the test piece and boxes for the input of the required report information were provided to ensure that pertinent data was collected whilst avoiding the operator spending an undue amount of time completing the report pro-forma given in the procedure. A copy of this sheet is shown in Appendix 5.

On completion of the inspection all the scale drawing sheets and rough working notes were collected. The operators were then given a de-brief as described in Section 8.

5 Aptitude Test Correlations

5.1 Analysis Procedure

The first stage in the analysis was to compare scores on the ability and personality measures obtained from the ultrasonic operators with norm data derived from a sample of 1930 UK adult males from a wide range of organisations and job types. This analysis was performed as a series of one sample t-tests\(^1\) in which the mean score for the operators' sample was compared with the mean score for the norm group.

The second stage in the analysis was to run a series of correlations\(^2\) and a principal components analysis\(^3\) on the dependent measures derived from the manual ultrasonic inspection tasks:

- Flaw omission frequency
- Average defect position error
- Average defect size error
- False positives (False calls)

This analysis was undertaken in order to determine the extent to which individual indices of ultrasonic test performance were inter-dependent and to determine if the separate measures could be combined to produce a single index of performance. The production of a single index

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\(^1\) A one sample t-test assesses whether there is a statistically significant difference between the average scores produced by two groups

\(^2\) A measure of the degree of the relationship between two variables, ranging from +1 (a perfect positive correlation) through zero (no correlation) to -1 (a perfect negative correlation)

\(^3\) Principal components analysis reduces data sets containing a large number of variables into a smaller number on the basis of their correlation
of ultrasonic test performance has the advantage of increasing the reliability of the performance measure. It also reduces the number of statistical tests to be performed with a resultant decrease in the likelihood of achieving a significant result due to chance factors.

If a single measure of ultrasonic test performance can be derived, then this could be correlated with operators’ scores on the ability tests, personality inventory and years of experience in undertaking NDT and manual ultrasonic inspections. Those variables demonstrating significant correlation with the single measure of ultrasonic test performance could then be entered into a multiple regression in order to determine their combined value as predictors of inspection performance.

5.2 Comparison with General Population

Table 1 below shows the mean scores on the ability tests for the ultrasonic operators and how these compare with norm data gathered from samples of applicants to a variety of jobs in various sectors of industry including engineering, transport and manufacturing.

Ultrasonic operators perform better than the average worker on tests of Numerical Estimation and Mechanical Comprehension. They perform less well than the average worker on tests of Spatial Checking, Fault Finding and Diagrammatic Thinking.

<table>
<thead>
<tr>
<th>Test</th>
<th>Norm</th>
<th>Op Data</th>
<th>t^5</th>
<th>p^6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following Instructions</td>
<td>21.18</td>
<td>20.68</td>
<td>-0.58</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Numerical Estimation</td>
<td>18.17</td>
<td>23.90</td>
<td>5.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mechanical Comp</td>
<td>14.35</td>
<td>17.40</td>
<td>4.01</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fault Finding</td>
<td>16.74</td>
<td>14.13</td>
<td>-2.84</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Spatial Checking</td>
<td>22.08</td>
<td>16.58</td>
<td>-4.76</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diagram Thinking</td>
<td>18.75</td>
<td>16.10</td>
<td>-2.46</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Table 1 Comparison of Ultrasonic Operator Ability Test Scores with Norms

Table 2 below shows the mean scores on the personality inventory for the NDT operators and how these compare with norm data gathered from a sample of male UK workers.

Ultrasonic operators score higher than the average male UK worker on Responsibility and Cautiousness. They score lower on Ascendancy and Sociability.

4 A statistical technique to determine the extent to which the scores on one variable (here, NDT performance) can be predicted from scores on other variables (here, ability test scores and personality scale scores).

5 t is the calculated test statistic for the one-sample t test. The larger the value of t (either positive or negative), the more likely it is that the difference between the mean scores of two groups is not due to chance.

6 p is the probability of the calculated value for a test statistic arising as a result of chance (random) factors. If the value of p is lower than 5%, i.e. p<0.05, then by convention the result of the statistical analysis is considered to be significant.
The importance of these differences between the operators’ sample and the norm groups will be dependent upon the extent to which these variables are correlated with ultrasonic performance.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Norm</th>
<th>Op Data</th>
<th>t*</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascendancy</td>
<td>23</td>
<td>20.90</td>
<td>-2.91</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Responsibility</td>
<td>26.9</td>
<td>28.9</td>
<td>3.20</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Emotional Stability</td>
<td>27.1</td>
<td>27.70</td>
<td>0.80</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Sociability</td>
<td>22.2</td>
<td>20.15</td>
<td>-2.43</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Cautiousness</td>
<td>23</td>
<td>27.05</td>
<td>4.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Original Thinking</td>
<td>26.6</td>
<td>25.05</td>
<td>-2.02</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Personal Relationships</td>
<td>23.9</td>
<td>22.59</td>
<td>-1.27</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Vigour</td>
<td>26.5</td>
<td>25.44</td>
<td>-1.51</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>

Table 2 Comparison of Ultrasonic Operator Personality Inventory Scores

* See footnotes 5 and 6 on previous page for definition of t and p.

5.3 Correlation with Ultrasonic Performance

As discussed above the principal components analysis, based on the correlations between the ultrasonic performance variables, revealed a single index of performance which correlated highly with each of the individual NDT dependent measures.

<table>
<thead>
<tr>
<th>Correlation with Single Performance Factor</th>
<th>Flaw Omission Frequency</th>
<th>False Positives (False Calls)</th>
<th>Average Position Error</th>
<th>Average size error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.629</td>
<td>.578</td>
<td>.818</td>
<td>.627</td>
</tr>
</tbody>
</table>

Table 3 Correlation between Single Performance Factor and Individual Performance Measures

These correlations between the individual ultrasonic dependent measures and the single index of performance were used to calculate an overall ultrasonic performance score for each operator. The overall performance is based on the combination of the individual error measures listed in Table 3 and is therefore a single measure of overall ultrasonic error.

The overall ultrasonic error scores were then correlated with operators’ scores on each of the ability tests. A significant negative correlation was found between the overall ultrasonic error performance scores and the test scores for Mechanical Comprehension ($r^7 = -0.352, N^8 = 37, p = 0.016$, one-tailed$^9$). Operators with higher Mechanical Comprehension have lower overall error.

$^7$ r is the calculated test statistic (correlation coefficient) for the Pearson Product Moment Correlation.

$^8$ N is the number of pairs of scores used in calculation of the correlation coefficient.

$^9$ A one tailed test is one in which the direction of the relationship (positive or negative) between two variables is predicted at the outset of the study.
ultrasonic error performance scores. One tailed tests were utilised here based on the conclusion in the literature review that NDT performance was associated with mechanical aptitude, spatial visualisation/abstract reasoning and general cognitive ability. Cohen (1992) argues that for $r$, coefficients of 0.1 should be considered small effect sizes, those of 0.3 medium effect sizes and those of 0.5 large effect sizes. The above correlation between overall ultrasonic error scores and the test scores for Mechanical Comprehension should therefore be considered a medium effect size.

Overall ultrasonic error scores were also correlated with each of the personality variables. Significant positive correlations were found between overall ultrasonic error scores and Sociability ($r = 0.354$, $N = 40$, $p = 0.032$, two-tailed$^{11}$); Cautiousness ($r = 0.387$, $N = 37$, $p = 0.02$, two-tailed) and Original Thinking ($r = 0.353$, $N = 37$, $p = 0.035$, two-tailed). Operators lower in Sociability, Cautiousness and Original Thinking have lower overall ultrasonic error scores. Two tailed tests were used in the analysis of these personality variables because the literature does not provide a sufficiently clear basis from which directional hypotheses could be derived. The above significant correlations between overall ultrasonic error scores and the personality variables should be considered as medium effect sizes.

A final set of correlations was computed between overall ultrasonic error scores and years of experience in both general NDT and manual ultrasonic inspection. These revealed a significant negative correlation between years of manual ultrasonic inspection experience and overall ultrasonic error score ($r = -0.315$, $N = 37$, $p = 0.028$, one-tailed). However, there was no significant correlation between years of general NDT experience and overall ultrasonic error score.

From the analyses described above, five variables were found to correlate significantly with the overall ultrasonic error scores:

- **Mechanical Comprehension**
- **Sociability**
- **Cautiousness**
- **Original Thinking**
- **Years of manual ultrasonic test experience**

These five variables were entered into a multiple regression to determine the extent to which overall ultrasonic error score could be predicted from the variables in combination. The correlation between the five variables and the overall ultrasonic error score was $R^{12} = 0.72$ which demonstrates that the variables account for 52% of the variance in the overall ultrasonic error scores. Of the variables entered into the regression equation, three were found to account for significant unique variance in overall ultrasonic error score: Mechanical Comprehension ($t = -3.12$, $p=0.004$), Cautiousness ($t = 2.54$, $p=0.017$) and Original Thinking ($t = 2.59$, $p=0.015$). Sociability and Years of manual Ultrasonic NDT experience did not add to the prediction of overall ultrasonic error scores, once the contribution of Mechanical Comprehension, Original Thinking and Cautiousness had been taken into account. Removal of non-significant predictors from the regression equation (i.e. Sociability, Years of experience), resulted in a regression model that accounted for 51% of the variance in overall ultrasonic error score. In terms of importance, the effect size is above Cohen’s characterisation of a large effect in which 25% of the variance is explained.

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$^{10}$ An effect size is a an index of the importance of the statistical relationship between variables

$^{11}$ A two tailed test is one in which the direction of the relationship between two variables is not predicted at the outset of the study

$^{12}$ $R$ is the multiple correlation coefficient representing a measure of the overall association between a dependent variable (here, overall NDT error score) and the combination of predictor variables used in the regression equation
5.4 **Conclusions**

From the analysis conducted above it can be concluded that, within this sample, overall ultrasonic error performance is related to scores on the test of Mechanical Comprehension and the personality variables Cautiousness and Original Thinking. Interestingly these variables are more powerful predictors of manual ultrasonic inspection performance than the number of years of experience an operator has in performing this task.

The results reveal that good manual ultrasonic inspection performance is associated with high scores on the test of Mechanical Comprehension and low scores on the personality variables Cautiousness and Original Thinking. The result in relation to Mechanical Comprehension is consistent with evidence presented in the literature review (Appendix 2) and confirms the importance of this ability for ultrasonic inspection.

The result in relation to personality scores may appear more unexpected. In the case of cautiousness, however, it should be remembered that the mean score on this scale for the ultrasonic operators was significantly higher than the norm for UK employed males. Thus those operators who score high in relation to other operators within the ultrasonic operator group could be described as over-cautious whilst those who score low in relation to other ultrasonic operators may in fact display a level of cautiousness which is consistent with the average UK male worker. Thus the results could be interpreted as showing that those operators who display an average level of cautiousness, in relation to the general population, are better suited to the ultrasonic inspection task.

In relation to Original Thinking, high scores on this variable suggest a tendency to seek novel solutions to problems or to find alternative methods for accomplishing a task. Low scores on this variable may be indicative of a person who is comfortable applying a ready made procedural solution to a problem, and may not seek to develop their own solution using alternative methods. Thus, the results suggest that those operators who have an overly original or non-standard approach to the manual ultrasonic task may produce more errors than those operatives who are inclined to follow a standardised procedure.

These results have implications both for the selection of new ultrasonic operatives and also for the training of existing operators. With respect to selection these results suggest that both ability test and personality scale scores can be used to select staff with appropriate characteristics for conducting ultrasonic inspections. In relation to training, the findings suggest that this should focus both on the development of ability, particularly focussing on mechanical comprehension, and on the development of self-awareness so that operators are able to recognise when they are acting in an over-cautious manner and where they might be applying procedures which are not compatible with those prescribed for the assessments undertaken.

6 **Ultrasonic Results**

6.1 **Operator Performance - Detection**

The usual method of expressing operator performance in trials such as these is to report the flaw detection frequency (FDF) i.e. the number of defects detected as a percentage of defects inspected. However, in view of the fact that each of the three test pieces contained a different number of defects it is probably fairer to use flaws missed as the measure of performance as was used in the correlation analysis described in Section 5.

Considering absolute flaws missed per operator gives the graph shown in Figure 3 whilst the graph of flaw missed frequency (FMF) per operator (i.e. the number of flaws missed expressed as a percentage of the flaws inspected which is $= 100 - FDF$) is given in Figure 4.
Figure 3 Plot of Number of Flaws Missed by Number of Operators

Figure 4 Plot of Flaw Missed Frequency (FMF) by Number of Operators
Figure 5 Average Flaw Missed Frequency per Test Piece

*Note the number in each bar on the chart denotes the number of defects in that test piece.*

The average results for the individual test pieces are shown in Figure 5.

### 6.2 Operator Performance – False Calls

There were 16 reported indications which did not correspond to any defect overall. These breakdown per test piece as follows:

<table>
<thead>
<tr>
<th>Test Piece</th>
<th>No. of False Calls</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2TP01</td>
<td>4</td>
</tr>
<tr>
<td>P2TP02</td>
<td>7</td>
</tr>
<tr>
<td>P2TP03</td>
<td>5</td>
</tr>
</tbody>
</table>

Only two operators reported 2 false calls with no operators reporting a higher number. 26 operators didn’t report any false calls. Apart from the fact that only 1 of the 11 operators with a 100% flaw detection frequency reported a false call, there was no obvious relationship between false calls and flaw detection.

### 6.3 Operator Performance – Positioning & Length Sizing

The positioning error was calculated for all reported defects by comparing the reported circumferential position of the centre of the defect on the outer surface of the pipe with the actual position. Where an operator reported more than one defect, the average positioning error and standard deviation were calculated. These results are shown as the blue diamonds with the associated error bars illustrating the standard deviation in Figure 6. The pink squares show the reported position measurements when operators just reported a single defect indication—hence no standard deviation and associated error bars.

The operators’ average or single positioning errors range from -17 to +28 mm with an overall average of +3 mm. Although the sign of the position error does not carry any significance from a structural integrity point of view by expressing the errors as a +ve or −ve it does show the variation observed in the results obtained from the ultrasonic inspection of the same defect.
Graphical Representation of Variation in Position Measurement Error Between Operators

Results from Individual Operators

- Error bars are ± the magnitude of the standard deviation indicating the spread of results forming the average.

The length measurement error for each reported defect was calculated by subtracting the actual length of the defect from the reported length. Hence a positive value indicates an oversizing and a negative value indicates an undersizing. Again, where an operator reported more than one defect, the average length error and standard deviation were calculated. These results are shown as the blue diamonds with the associated error bars illustrating the standard deviation in Figure 7. The pink squares show the reported length error measurements when operators just reported a single defect indication – hence no standard deviation and associated error bars.

The graph omits one length measurement error of 117 mm which was too large to display. Ignoring this error, the operators’ average or single length measurement errors range from -28 to +23 mm with an overall average of -2 mm.

Figure 6 Graphical Representation of the Average / Single Defect Position Errors

Note:
- Error bars are ± the magnitude of the standard deviation indicating the spread of results forming the average.
6.4 Defect Detectability

All defects were detectable using the procedure applied. This is confirmed by the results which showed that the highest miss frequency for any defect was 58% i.e. 58% of the operators who inspected for this defect missed it. Conversely, the least missed defect was missed by only 13% of the operators who inspected for it.

Overall the average flaw miss frequency for the individual defects was 36% with a standard deviation of 14%.

Full details of the performance measured on each of the defects are given in Appendix 7.

6.5 Summary

Once again the results obtained in this project are consistent with those obtained in the previous PANI projects and with other reliability projects conducted elsewhere: the average FDF for each test piece ranging from 58% to 67%.

This project probably had more false calls than the previous PANI projects but this is not surprising as the test pieces were designed to test the operators’ decision making processes and the geometry was selected because it had potentially confusing geometric echoes. However, the number of false calls was not considered excessive.
The positioning and sizing errors also show similar variation to that observed in other projects. The length sizing probably shows a larger variation although these two errors are not totally independent as the position of the centre is dependent on the identification of either end of the defect. Again, the presence of the geometric echoes will affect the sizing measurement.

It is important to note that all the defects were detectable and it was possible to detect all the defects in each of the three test pieces within the time allowed for the inspection. The fact that no defect was detected by all the operators who inspected for it whilst no one defect was missed by all operators shows that the test pieces were sufficiently challenging to provide a spread in operator performance results for comparison with the aptitude tests.

7 Theoretical Questions

7.1 Analysis of Results

The use of theoretical questions was initially seen as an additional way of gleaning information regarding an operator’s decision making process. In the Interim Report (see Appendix 2), it was proposed that the operators were to be shown a few diagrams of defects in a component and asked to describe how they would expect to detect them and show that they were present. The theoretical defect assessments were to cover two defects in a different geometry to the test pieces.

However, soon after commencing drafting the questions it became apparent that there was a potential problem with maintaining the security of the questions and that a large number of questions would therefore be required. This then created an additional problem if the questions were to be used as part of the performance measures: the questions would need to be of similar difficulty.

It was agreed that the questions would just serve as an additional source of general information on the overall level of operators’ understanding of the manual ultrasonic task. Rather than limit the questions to defect scenarios, questions on the QA aspects of the task were also generated. Sixteen questions were produced and each operator was given 2 questions to answer. Hence each question was answered by 5 operators. The full list of questions and the expected answers are given in Appendix 8.

In assessing the results described below, note:

1. Question 14 was a single line of text at the top of a page and two operators failed to provide an answer. It is likely that this was due to them not noticing this second question and so their null scores have not been included in the results.
2. One operator, answering Q15, stated that he had not had training on transfer correction and so didn’t attempt the question. This null score has not been included in the results.
3. In answering Q7, three operators didn’t remember / know the echo dynamic patterns and so were given diagrams showing them. These three scores have been included in the results.
4. Each question was marked out of 10.

In the light of the above there are a total of 77 answers included in the results. Figure 8 shows the average score for each of the sixteen questions whilst Figure 9 shows the distribution of the scores achieved by the operators.

The two questions the operators found most difficult were Q15 and Q12. Question 15 was on transfer correction and attenuation. Question 12 was on the checks made on flaw detectors and probes and on documentation.

Other questions which generated average marks of 5 or less were:
Q1 - This question was on the detection of and the signals produced by a LOSWF defect. Marks were lost because most operators did not describe the specular reflection off the defect and down to the backwall that would be seen with the 60° probe and would plot out on the far side of the weld.

Q4 - Again this question was about the detection of and the signals produced by two vertical defects. Marks were lost because operators were not conversant with other techniques, such as TOFD, tandem and self tandem, which could be used to detect vertical defects.

Q6 - related to operator qualification requirements and the different types of qualification. Poor marks were obtained because of lack of knowledge of the documents which would state operator qualification requirements and also lack of awareness of the different qualification schemes.

![Average Mark Achieved on Each Theoretical Question](image)

**Figure 8 Average Mark Achieved on Each Theoretical Question**

The best answered questions were questions Q10 and Q14. Q10 related to how an ultrasonic inspection would be affected by features of a component and the flaws produced by stress relief. Q14 required the operators to list the information that should be included in an inspection report.
7.2 Summary

It is not possible to derive any quantified conclusions from the results of the theoretical questions because the questions had not been normalised to provide a consistent level of difficulty and the small sample size – 5 operators per question – cannot preclude individual effects influencing the results. However, this was not the objective of the questions. Bearing in mind the small sample size, the operator being put on the spot to answer the questions and the context of answering the questions in the latter part of a long day of activities, it is possible to draw some generalised conclusions from this part of the work:

1. The operators appear to have a good knowledge of what could be considered everyday practice e.g. features of a component that would affect ultrasonic inspection and what needs to be in an inspection report.

2. However, there is an apparent deficiency in knowledge of information which may only need to be called on infrequently. This includes both QA which supports the everyday manual ultrasonic practice and a deeper understanding of ultrasonics and ultrasonic techniques.

8 De-brief and Observations

The second objective of the experimental work was to investigate the decision making process of the operators. This was undertaken by observing the operators during the inspections of the test pieces and de-briefing them once they had completed their inspection.

8.1 Methodology

The operators were questioned on two defects, if reported, and two geometric indications.

The de-brief was planned around set questions to ensure a consistent approach with all operators. The questions were based around the factors identified by Harris [Ref. 6] and described in the Interim report (Appendix 2). They were aimed at establishing how the operators had used information from the ultrasonic A-scan in deciding whether to sentence an indication as a defect, and hence reportable, or a geometric response.
Idealised answers to each question were generated for each of the defects in the test pieces prior to the experimental work. One intention was to use the comparison of actual responses with the ideal as a performance measure. Fortunately, this was not needed as it soon became apparent that eliciting the desired answers from the operators was not as straightforward as had been anticipated. The operators were obviously unused to providing explanations of their reasoning. It was often difficult to make them understand exactly what information was required without actually influencing or prompting the answer. Interrogating the operators regarding defect indications which they had missed was not undertaken for two reasons. The first was security of data: the operators were more likely to remember details of the defect indications they were questioned on than on the ones they had reported where they didn’t know if they were correct or not. Secondly, as defect indications can be “not reported” for a number of reasons, the operator would not necessarily remember having seen the indication and therefore be unable to provide credible answers.

The answers to the de-brief have been assessed and general conclusions reached. These are discussed below. One such conclusion was based on the supervisor observing the way the operators worked as well as their de-brief information. This conclusion was verified by an assessment of the video footage recorded during the experimental work. The footage of selected operators who had been ranked high, middle and low in the ultrasonic error classification was analysed.

8.2 Results

The signal features and the responses they generated are described below:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Possible Answers</th>
<th>Results &amp; Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amplitude?</strong></td>
<td>Indication recordable or not recordable</td>
<td>This feature was generally used to decide on whether the defect was recordable or not recordable.</td>
</tr>
<tr>
<td>What does this tell the operator?</td>
<td>Large amplitude – large reflector, near normal incidence</td>
<td>6 % of respondents correctly characterised the defect on the basis of the amplitude</td>
</tr>
<tr>
<td></td>
<td>Small amplitude – small reflector, of normal incidence or rough reflector.</td>
<td></td>
</tr>
<tr>
<td><strong>Echo Shape?</strong></td>
<td>Single source</td>
<td>Rough cracks appear to be easier to characterise on the basis of echo shape,</td>
</tr>
<tr>
<td>What does this tell the operator?</td>
<td>Multiple reflectors or rough reflector</td>
<td>13 % of respondents correctly characterised the defect on the basis of the echo shape</td>
</tr>
<tr>
<td><strong>Position?</strong></td>
<td>Plot on cross section drawing</td>
<td>91% of the respondents positioned the defects correctly in the cross section. The position of the indication was used to assist in deciding if it was a defect indication.</td>
</tr>
<tr>
<td>Did the operator plot out the indication? How?</td>
<td>Indication positioned within component displaced from geometric sources.</td>
<td></td>
</tr>
</tbody>
</table>

Previous PANI exercises have
highlighted the variability in quality of plotting of the defects.

| Echo Dynamic? What does this tell the operator? | • The echo dynamic would allow the nature of the reflector to be established – point, smooth, rough normal, rough oblique. | • Surface breaking cracks appear to be easier to characterise on the basis of echo dynamic. 32% of respondents correctly characterised the defect on the basis of the echo dynamic. It is worth noting that the theoretical questions highlighted that the operators were not as familiar with the different echo dynamic responses as may be expected. |
| Persistence? | • An echo that persists around the circumference of the component is likely but not to be a geometric echo. • An echo which appears for a finite extent in various directions is likely to be a defect indication. | All operators reported that the indications had length. Specific geometric echoes were easily identified by their persistence all the way around the component coupled with the consistency of both the echo static and echo dynamic. |
| Reference Comparison? | • The comparison of a suspect echo with a reference reflector or known defect to establish similarities or differences. This is a simplified visual check on position, amplitude and shape. | This comparison was not undertaken in this inspection: there was no reference test piece other than the DAC block. It is worth noting that in PANI 2 at least one operator used a training sample as a reference to assist in the interpretation of echoes from the actual test sample. |

For each ultrasonic response that the operator was de-briefed on, the above investigation was performed on the main probe which detected that defect and subsequently on a supporting probe. On completion of the details of the main probe, the following decision process steps were established:

**What was the operator’s overall deduction from this probe?**

46% of the respondents correctly characterised the defect indication using the main probe. Cracks were the flaw most correctly characterised.

**Did the operator decide the sentencing on the basis of this probe?**

54% of the respondent sentenced the indication on the basis of the main probe and 46% would not.

**Did the operator propose how he might test out his thoughts with subsequent probes?**

80% of the respondents said they would use other probes to support the main probe.
Did the operator apply knowledge during the inspection by putting it in the form of IF-THEN logic?

44% of respondents were not familiar with the term IF-THEN logic. From the previous question 80% of respondents had said that they would use other probes to support the main probe but only 29% had thought which probe to use.

So a high level of logic is being applied by 51% – IF a similar indication is detected on a second probe, irrespective of the actual probe, THEN it confirms the presence of a defect. But only 29% are applying the logic IF the x° probe shows an indication which may be due to toe crack / LOSWF etc THEN a y° probe should also give an indication in the same place.

Did the operator throw away information from consideration during the process of reaching an inspection conclusion?

46% of respondents did not sentence the indication on the main probe and 80% said they would use a second probe to support the main probe. So 34% are looking for confirmation of the presence of the defect as sentenced by the main probe whilst 20% look for no further information. This means 54% of operators are not considering all the potential information which could be obtained from the scans before deciding on the source of an indication.

8.3 Summary of Decision Making Analysis

The de-briefs generated the following information regarding the operator’s decision making processes:

• Generally, the operators had no problem describing why the geometric indications were not reportable based on persistence and consistency of both the echo static and echo dynamic patterns.
• The operators were not comfortable with verbalising their reasons for reporting indications. This has a number of implications:
  – The decision making has become an instinctive skill
  – The decision making is not well defined
  – Operators are not often asked to explain their decisions
• Most operators make a decision before gathering all the information on a potential defect
• Knowledge of ultrasonic / defect interactions is not used to assist the majority of operators to make the report / not report decision.

8.4 Decision Making in Detection and Characterisation

Whether the above summary has implications for the current application of manual ultrasonics depends upon the importance attached to the operator’s ability to apply simple and complex decision making strategies.

Many acceptance criteria specify just amplitude and length and through wall dimensions for unacceptable indications. Common defects detected with a 0° beam are sentenced based on the dimensions of the indication and its position through wall. Hence, for defects which give clear signals, away from geometric features, this simplified decision making strategy is sufficient. Detection is based on single signal characteristics and characterisation of the source of the indications is not required. Incorrect characterisation of a defect is not a criterion for automatic failure of a PCN examination (PCN is the UK’s National Central Certification scheme for the certification of NDT personnel).
However, in complex geometries, when there is a need to discriminate between defect indications and variations in geometric echoes, data from more than one probe needs to be assessed to achieve correct detection of defects. Combination of data from multiple probes requires some degree of characterisation of the source of the echoes. So detection cannot be totally separated from characterisation.

The test pieces used in the experimental work were challenging and included responses from several geometric features. As such, the operators would have needed to be able to apply both simple, single probe and multiple probe assessments for confident, reliable detection. They would also need to know which was the appropriate assessment to apply.

From the above and from the theoretical questions it can be concluded that, for complex manual ultrasonic inspections, there are knowledge gaps in the application of ultrasonic / defect interactions and in awareness about the decision making process.

These gaps can be resolved in two ways:
- Operators are given training to remove these knowledge gaps
- The decision making process is specified precisely in procedures for complex geometries

As the latter is not going to be able to predict beforehand every possible scenario, both will need to be applied to a greater or lesser degree.

8.5 Overall Observations Regarding the Inspections

8.5.1 Observations Made During Invigilation of the Inspections

Overall, the observations made during the inspections led to the following conclusions:

- Operators must be able to understand the ultrasonic implications of the geometry in order to perform well.
- The better performing operators applied the procedure in a methodical way – see below for further explanation.
- Even the better performing operators can mis-characterise an indication

The better performing operators who used a methodology for the inspection achieved the aims of the procedure through a systematic way of working:

- They started by reviewing the procedure and obtaining clarification where necessary.
- Once they decided on their methodology they would stick to it.
- They plotted out weld toes & unfused land on pipe with 0° probe
- They completed 0° scans on outside of pipe and the disc
- They completed angle beams on disc and the outside of the pipe
- They resolved all geometrical indications and recorded all recordable indications.
- They evaluated all recordable indications
- Finally they produced a comprehensive report

By applying a methodical approach, the inspection of the weld can be split into zones, hence simplifying the inspection.

8.5.2 Post Trial Observations

In order to complement the observations made during the actual trials (see previous section), a review of the CCTV footage taken from a selection of candidates during the trials was completed. The candidates for the review were selected on the basis of their performance during the trial to ensure that a range of candidates covering the distribution of performance were included in the analysis.
The aim of the observations was to review the candidate's approach to the task, their scanning technique and to identify their application of the procedure. The CCTV footage consisted of two streams, one focused on the candidates’ working area and one closely focused on the test piece. It was possible to observe the actions of candidates from a combination of both streams, however occasionally the candidate would temporarily obstruct the camera (for very short periods of time), or leave the field of view where they could not be seen (often for refreshment or toilet breaks). Overall, it was possible to clearly ascertain the candidates actions at a high level.

As CCTV analysis is time-consuming, observations were made of 12 of the 40 candidates who underwent the trial, and some conclusions have been drawn from the footage. It must be made clear that these observations are post trial and have therefore not involved any discussions with the candidates and are independent to the de-briefs completed during the trial. However, this exercise has produced some interesting points which contribute towards the outcome of the study.

The candidates which were ranked as the highest performers, i.e. achieving 100% in the number of defects detected with no false calls, demonstrated a clear difference in approach to those with the lowest performance. For example, the highest performers displayed an air of confidence and even during setting up appeared more direct and effective. Throughout the duration of their inspection, the highest performers appeared focused and were not easily distracted, which they maintained until completion of the task.

The highest performers were task oriented and appeared to ‘get on with job’. With regards to their technique, they were consistent and methodical demonstrating good surface coverage whilst being efficient and thorough.

From the observations it was possible to determine that although the procedure was read through initially, and often referred to throughout the inspection, it was not being fully completed as intended. Candidates would tend to read through the procedure and then apply their version of the required scans in order to complete the task. All the specified probes were not always used and were often not used in the order specified. However, the candidates were not hesitant in their approach to the task and appeared to be aware of the task requirements and were clearly successful in both their selection of probes and choice of scans.

In comparison, the lowest performers, or those candidates scoring 0-25% defect detection rates with a range of false call scores tended to be unorganised and changeable in their approach to the task. They seemed hesitant and often took a long time to get started with extensive calibration times and on a couple of occasions had difficulty calibrating at all. In one case, the candidate did not appear to understand the task requirements. The observations showed the lowest performers to be experiencing problems with the task, procedure and the equipment, requiring intervention or explanation from examiners.

They appeared unconfident and uncertain and their technique was inconsistent and haphazard. They did not appear to cover the surface area well and often appeared to have missed large sections, whilst spending considerable time repeating scans on certain areas.

The lowest performers tended to be easily distracted and were often observed discussing the task with other candidates, chatting and leaving the examination area for long periods. Consequently, the task did not appear to be fully completed in the time provided.

They appeared unsure about the procedure and spent considerable time reading and referring to the procedure however, they generally did not complete all the required scans in the specified order with the specified probes. They applied the procedure in their own way and performed badly.
It was difficult to draw clear conclusions from the review of the candidates who had achieved average performance. They showed a combination of the behaviours observed from both high and low performers but at varying degrees.

To summarise the points made above, the findings of the CCTV observations tend to support the conclusions drawn from the actual trial observations. The implications for the findings are that there are clear characteristics displayed by the ‘good inspector’, for example; confidence, efficiency and motivation. However, this raises the question that these characteristics could be attributable to the most desirable employees in any industry or organisation i.e. are these exclusive to NDT? It is possible that these characteristics are desirable in any employee.

However, inspectors who performed particularly well also displayed characteristics such as; focus, attention and/or diligence and when combined with characteristics such as confidence, efficiency and motivation it may be that an appropriate mix is achieved which could contribute to the skills required for the ‘good NDT inspector’.

The observations also showed that each inspector applied the procedure differently, and of those observed, none appeared to complete all the required scans, and all scanned in a different order with different probes. The use of operating instructions is paramount in inspector reliability, and the existing procedural formats are not conducive to good, reliable inspector performance.

Taking into consideration the comments made during workshops with regard to the organisational aspects of NDT and the current procedural system, the development of an improved competence based management system, including effective and appropriate procedures and operator aids is required. This system would support individuals of all levels to ensure that all inspectors posses the right skills, support and information to complete the tasks assigned to them.

8.6 Procedure Improvements

The procedure (PANI 3 01 – see Appendix 5) was written in line with the standard BS EN 1714. It was provided to all candidates for the inspection of the PANI 3 test pieces. The procedure allowed the operator a degree of freedom in how to actually apply the specified scans. In addition the procedure had a number of deviations from what may be considered human factors relevant to good practice in procedure writing.

It became clear from inspection observations both during trials and post trial investigations, that operators were not necessarily reading the full procedure, or applying the procedure as it was intended to be used during the inspection. With this in mind, a review of the procedure was completed from a human factors perspective to identify potential improvements which may encourage the full use of procedures during inspections. The findings of this review are as follows:

8.6.1 Length and Structure

The procedure is extremely lengthy and wordy and a significant proportion of the procedure includes the presentation of information, which should be read prior to the commencement of the inspection. Information is also presented as long sentences where short sentences would be sufficient. Long sentences overload the memory system, whereas short sentences are easier to read and recall. The actual procedure, i.e. the specific tasks to be completed by the operator, is not presented until page 8 of 11.

It is important that a procedure provides all the required information for a particular task to be completed, however the inclusion of unnecessary information, or presentation of information in long form, is likely to result in the operator skim reading or discarding the majority of information,
particularly where time is limited. Procedures should be short and to the point and should only contain the information required to complete the task.

8.6.2 Content and Presentation of Information

The content of the information presented in the early parts of the procedure is a combination of information, requirements, pre-requisites and procedural steps. In addition to this, there is a large amount of information which is redundant and unnecessary and significantly increases the length of the procedural information.

For example, Section 1 Scope, describes the reason for the procedure and a brief description of the aims of the procedure and the inspection. This section also states that the procedure meets the requirements of BS EN 1714. The majority of this information has already been presented on the front sheet of the procedure and the existence of a Scope section is questionable.

Section 2, Personnel, uses a complete section to state that the procedure must be completed by a qualified inspector and identifies the required qualifications. This information would be better presented in short form on the front sheet, where it would be easily seen.

Section 3, Equipment. The information presented in Section 3 is required for the correct application of the procedure but is presented in an extended form and therefore takes up a full page of the procedure. If the information was rationalised to ensure that only the required information was included, an equipment table could be inserted which would clearly state the required equipment and would provide a more useable format for operators to quickly check that they have the required equipment to complete the task.

Presenting procedural information in the style of a report such as this, extends the length of the procedure and make it difficult for operators to access important and essential information. The information should be grouped according to type (i.e. requirements, pre-requisites etc.) and should be short and to the point with all non-essential information removed.

8.6.3 Procedural Steps

The procedural steps, or the start or completion of the tasks required are not clearly identified. The section which provides the procedural information is titled ‘Scan Diagram’ and lists the required scans in a tabular form underneath a diagram of the test piece. However, although the scans are numbered, it is not clear whether all scans must be completed, or whether the order of completion is important. In addition to this, there are some procedural requirements, not included within this section, but distributed amongst Sections 7 – 9, which are essential to the successful completion of the tasks.

In addition, the ordering of the information within Sections 7 – 9 is not based around how the task is performed, which makes it more difficult to use. For example, examination and evaluation each have separate sections, when in reality these two tasks would be done in quick succession for each part of the item being inspected. Therefore, it would be more logical to order the procedure around the item being inspected, with the different examination and evaluation requirements embedded, as opposed to being presented with all the examination tasks grouped together and all of the evaluation tasks grouped together, as this leads to more unnecessary movement around the procedure.

The task steps necessary to achieve the task should be provided in appropriate detail and written in short and identifiable steps. Task steps should start with an action verb and there should only be one action per step. The operator should not have to perform mental arithmetic, i.e. where possible accurate information should be provided.
Task pre-requisites and requirements should be clearly identifiable and accessible. If provided immediately prior to the task steps the operator can ensure that the pre-requisites are met and requirements are acknowledged.

Each task step should be numbered (using a system which does not extend to more than three layers), and if the sequence of task steps is important this should be stated.

8.6.4 Procedure Format

The procedure is presented in a mixed case text, and is in line with best practice on the presentation of procedures, however there are a number of points to note which may provide improvements to the current format:

– The use of bold and underline text can be used to highlight text where added emphasis is required (for example, warnings and cautions or safety requirements).
– The use of capitals for long sentences should be avoided and underlined capitals should not be used.
– Text should be left justified as people use the right jagged edge of the text to help keep their place.
– Use clear headings which reflect the information which follows.

8.6.5 Record-Keeping

Currently, the procedure has no checking off provisions or other means of place keeping or acknowledging completion of significant task steps. The provision of initialling or signing off task steps encourages the operator to complete all the required steps and helps the user to keep their place within the procedure. In addition to this, signing off provisions allows the operator to take responsibility for the completion of the procedure.

For this particular procedure, if each scan required a signature, it is more likely that all scans would be completed.

8.6.6 Summary

A number of the comments within this section relate to the selected format of the procedure and whether this is appropriate for all instances of how it is used, that is, as a training document and as a document for use while completing the task. The following bullet points summarise the key issues and further guidance on writing procedures is contained in Section 8.7:

• If it is intended for training purposes then it should contain detailed information on what is being done, why it is being done, along with in-depth information on how to do it.
• If it is intended for on-the-job use to support reliable operations, it should be succinct, contain only pertinent information that can help a SQEP operator complete the task reliably and presented in an easy to use format.

Acting on the critique given above, the PANI 3 procedure has been re-written into what is considered to be a better procedure for providing the operator with the relevant information, ensuring that the inspection is applied in the optimum methodical way and reducing the potential for error. This proposed procedure format is given in Appendix 9.

8.7 Procedure Writing – Human Factors Considerations

8.7.1 User Centred Design

A user centred design approach should be adopted when producing procedures to ensure that they take account of user requirements and are in a format consistent with the task, and the environment within which it is being completed. Adopting such an approach will help to reduce
the likelihood of errors and intentional violations, and ensure that they are valued and used by the end user.

Procedures are a key part of any competence based management system, and they have an impact on three key areas:
- training and assessment of personnel,
- on-the-job support to reliable operations, and
- monitoring, recording and reviewing performance.

Procedures (or sub-sections thereof) should be produced with an understanding of the user, the task and the environment, by gathering the following information:
- What is the purpose of the instruction (training, on-the-job support, compliance etc.)?
- Who will use the procedure? What are their skills, experience, training and needs?
- How often is it completed and how complex/ difficult is the task?
- How much information does the user require?
- What is the working environment like, and what impact does this have on format?

This process is completed in order to determine:
- whether both training and on-the-job procedures are required,
- what level of information should be included in the various formats required to ensure reliable operations, and
- what format should the different procedures take in order to be usable and used.

8.7.2 Selecting Procedure Format

1. Long Form

The long form procedure* is the primary source of information containing detailed steps of how to complete the operation. Its primary uses are:
- a training document, and
- a reference document for experienced users when required.

* This could be a step-by-step instruction or training manual format, whatever is seen as more appropriate.

As the long form procedure is used for training purposes, it contains considerable detail and may be lengthy and unsuitable for use on the job. For this reason a more concise, short form instruction is often more suitable for use at the workplace.

2. Short Form

Short form procedures are concise, easy to use documents which contain a summary of key steps and important information for reference and/ or signing-off while completing the job. If the answer to any of the following questions is ‘yes’, it is likely that a short form document will be of benefit to the user:
- Does the procedure have any requirements for the operator to sign-off certain steps for compliance purposes?
- Is the order of any complex processes key to successful completion of the task?
- Does the procedure contain key information, settings etc. that are useful to have accessible while on-the-job, as opposed to recalling them from memory?
- Would a checklist type instruction make the operation easier to follow and/ or more reliable by bringing key information together in one place?
8.7.3 General Guidance for all Procedures

Structure and Content

The structure and content of operating procedures should be based upon a task analysis of the activities undertaken when using the procedure. This ensures that the document structure and the information contained therein provide the user with the information they require in an understandable and accessible form. The following are some principles and requirements that are generally associated with long form and short form procedures:

Long Form Procedures
Due to these being primarily training and reference documents, the following are key requirements:

- They should be comprehensive, containing enough information to allow an inexperienced user to understand the task requirements and complete the task safely and reliably.
- They should contain adequate background/introductory information to aid understanding of inexperienced users.
- They should clearly convey what is being done, why it is being done and how to do it.
- They should be structured logically around how the task would be completed in reality (there can be a tendency to structure procedures on an equipment/system basis, but if this is not how the tasks are completed it can lead to unnecessary movement around the document and cross referencing).
- Introductory sections should include a clear purpose of the procedure, the intended user and their training requirements, any precautions or hazards and any with special tools/equipment required to complete the job.
- The actual operational sections should be clearly distinct from the introductory/background sections, and it should be obvious to the reader which section they are in.

Short Form Procedures
Short form procedures are for use ‘on-the-job’ and can come in a variety of formats including checklists, flowcharts and notated diagrams. The following are key requirements.

- Short form procedures are not always required. The potential consequences of getting the job wrong, task complexity and task frequency should be taken into account when determining whether a short form procedure is required, and how much information should be contained therein.
- They should only contain pertinent steps and/or information which will help an experienced user complete the job reliably. If they contain too much information they are unlikely to be used.
- They should be produced in partnership with the end user. This is essential in order to determine the information that is required and that which is not.
- They should contain essential settings, levels, etc. and should prompt the user of ‘what to do’ as opposed to ‘how to do it’. The detail of ‘how to do it’ is contained in the long form.

8.7.4 The Written Word

Good quality written English within procedures is essential in reducing the likelihood of errors. The guidelines below, if followed, will help to produce procedures that can be understood and followed easily and reliably.

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Supporting Information/ Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Write steps in the active voice.</td>
<td>‘Open Valve 123’ is better than ‘Valve 123 should be opened’</td>
</tr>
<tr>
<td>2. Ensure steps are unambiguous by stating exactly what is required.</td>
<td>Avoid using ‘approximately’, ‘about’ or ‘as appropriate’.</td>
</tr>
<tr>
<td>Guideline</td>
<td>Supporting Information/ Example</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>3. Ensure steps are short and to the point.</td>
<td></td>
</tr>
<tr>
<td>4. Use only one action per step.</td>
<td>Numbered, indented lists can help to achieve this.</td>
</tr>
<tr>
<td>5. Write steps in the order they are performed.</td>
<td>‘Cut the red wire, then cut the green wire’ is better than ‘Cut the green wire when you have cut the red wire’.</td>
</tr>
<tr>
<td>6. Write ‘what to do’ instead of ‘what not to do’.</td>
<td>‘Maintain the temperature above 500°C’ is better than ‘Do not let the temperature fall below 500°C’.</td>
</tr>
<tr>
<td>7. Avoid double negatives.</td>
<td>‘Ensure level is above 100 before continuing’ is better than ‘Do not continue if level is not above 100’.</td>
</tr>
<tr>
<td>8. Use consistent language that users are familiar with.</td>
<td>Avoid using jargon and technical terms that users might not be familiar with.</td>
</tr>
<tr>
<td>9. Ensure where terminology and abbreviations are used, they are used consistently.</td>
<td>Provide an explanation of all acronyms.</td>
</tr>
<tr>
<td>10. Use acceptable ranges and avoid using absolute values unless equipment can be read to the level required.</td>
<td>Only use absolute values where the accuracy of the measuring device allows this to be done reliably.</td>
</tr>
</tbody>
</table>

### NDT Organisation – Analysis of Current Practice

The literature review, described in the Interim Report (Appendix 2), reported that unreliability in manual ultrasonic inspection is not the product of one single factor but a combination of interrelated factors associated with the job, the individual and the organisation. The ‘organisation’ can have a significant influence on individual and group behaviour, and includes such factors as:

- planning
- safety
- communication
- management
- culture

A recommendation of the literature review was that work be performed on the organisation and organisational support for NDT (including the type and nature of the industry) and that this work should look at the level of support given to NDT operators to assist them in the task and to minimise the effect of potentially negative factors.

This supported the original decision to undertake an assessment of how the quality of the manual ultrasonic process is assured. This had already started by asking operators in a workshop environment to describe both actual and idealised processes for manual ultrasonic inspection. Following the operator workshop, companies were approached to elicit their viewpoint on the application of NDT in general. It was considered more beneficial to ask companies what they considered to be the major risks to achieving a quality inspection. The outcomes of the workshop and the company views are presented below.
9.1 Review of Workshop Results

The ideal process from the operator’s point of view, irrespective of the employment contract environment, is one where the preparation for the inspection is undertaken by the management of the NDT organisation. All the relevant information is then passed to the operator on mobilisation. Apart from undertaking site preparation such as inductions and permits to work, the operator just concentrates on the main task of conducting the inspection and producing a report. The NDT organisation then takes over to technically review and formally issue the report.

Although the operators looking at the ideal jobbing inspection process didn’t identify a plant visit to check on surface condition, access and safety like the other two groups, they did suggest that consultation between the NDT vendor and the client should include digital photographs of the test component so as to avoid surprises on arrival at site.

The actual processes tend to deviate from this ideal the more temporary the contract environment. Consequently operators working on long term NDT contracts or employed as in house NDT operators work closely to the ideal whilst the jobbing inspection environment is more prone to deviation from the ideal.

The further the process moves from the ideal, the more additional activities fall upon the operator with the consequential distraction and impact on the actual inspection task. Whilst no process is perfect and conscientious employees will endeavour to overcome process deficiencies to achieve the required task, the limit on what is acceptable is not clearly defined and often falls upon the individual operator to determine.

The ideal processes also involve a number of key documents, starting with an outline specification. The client is then asked to provide information and approve the outline or to host a visit at which information is obtained. The outline specification and the additional information is then developed into a work package which includes procedures, risk assessments, standards, acceptance criteria, access and cleaning requirements, drawings and photos and equipment inventory. These provide the operator with all the information necessary to conduct the inspection. Two way communication between the operators and their immediate supervisors, and possibly client staff, in the form of a briefing or discussion was also seen as important prior to performing the inspection.

During the open discussion the operators agreed that information and preparation are both key to a good inspection and that greater client awareness of NDT was required. The discussion also generated suggestions for potential improvements:
- Adequate time to set up and conduct the inspection
- Less monetary pressure on operators
- More time given to training, both trainee and trainer
- Better innovation of equipment
- Operators to work in pairs – this was believed to improve safety and productivity

9.2 Process Risks

Human nature being what it is, it is unlikely that NDT vendor companies would admit to any difference between their current NDT processes and an ideal process. In order to elicit views on where improvements could be made, companies were asked to identify the biggest risks to achieving a quality inspection. Identifying risks to business offers a greater chance that improvements to the process in the form of mitigations can be agreed by the industry as such mitigations will deliver commercial benefit.

Without exception, the NDT vendor companies see lack of information from the client as a major risk to achieving a good inspection. This arises from a general lack of knowledge of NDT by the client. A typical problem is that standards are specified by the client but hard copies are not available or the NDT vendor does not consider them to be appropriate. For manufacturing
inspections, it also includes lack of availability of fabrication knowledge which has to be gleaned through relationships with individual welders.

Both the likelihood and the consequences of this risk were classed as high. The consequences impact on the NDT vendor company through:

- Unrealistic expectations on behalf of the client
- Time delays in doing the job brought about in part by mobilisation with:
  - wrong equipment
  - wrong personnel
- Adverse impact on personnel which affects performance of the inspection

The consequences to the client are time, and hence cost, in completing the job, and also a lower quality of the job performed. In all instances the client is considered to be responsible for this risk: the client being the organisation that has the wherewithal to do something about it.

Another risk judged to have both high likelihood and high consequence is poor preparation for the inspection. This includes surface finish, access to the component and also the expectation that inspection can start when the component is still hot. The client is the organisation which can mitigate against this risk which is due to their lack of knowledge of NDT issues by the client. This is more prevalent in small companies than in larger ones.

Other general risks, classified as medium likelihood but potentially high consequence and owned by the client, are shown in Table 4. Sub-standard supervision is a QA issue of contract management and is possibly exacerbated by the difficulty of interfacing the client’s QA system with that of the NDT company.

Commercial pressures will always be present but the combination of lack of knowledge of their impact on the application of the NDT and the fact that errors in the application of NDT are not likely to come to light, if at all, until some later date means that this risk is usually not properly assessed. A suggested mitigation for this risk, made at the operator workshop, is to make the inspection the responsibility of the organisation who will carry the consequences of any deficiencies. This may be the purchaser of the component rather than the manufacturer or alternatively the local council of the area where the plant will operate.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Owner</th>
<th>Likelihood</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sub-standard supervision by client of NDT company</td>
<td>Client</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>2 Commercial pressures</td>
<td>Client</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>3 Long winded/non standard reporting systems</td>
<td>Client</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

**Table 4 Medium / High Classified General Risks Owned by Client**

The risks identified which pertain to operators are shown in Table 5. The high likelihood and high consequence of the effects of shift work on operator performance was also highlighted by the operators themselves in the workshop. Both companies and operators want long concentrated periods of work: the companies because of commercial and technical demands; the operators to maximise income. A lot of work has been performed to investigate the effect of shifts and long hours on concentration and this is reported in part in Section 10.2.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Owner</th>
<th>Likelihood</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Effect of shift working on operator concentration levels</td>
<td>Client</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
The gaps in operators’ knowledge identified in Section 7 above correspond to risk 5 in Table 5. This is a training issue which needs to be addressed by both individual NDT companies and the profession as a whole. Operator attitude impinges on a number of areas of this project. The Interim Report (See Appendix 2) describes the “ideal operator” in Section 5.2.4. Top of the list of characteristics was integrity, defined as the confidence to say “I don’t know”. This confidence does not just exist in isolation and can be encouraged or destroyed by the culture / environment in which the operator is asked to work. Section 5 illustrates how personal traits can impact performance. Awareness of such traits supported by open and honest communication can assist both the organisation and the operator to manage them and avoid undesirable (from both viewpoints) situations arising.

Finally, the quality of messing facilities is just a specific example of creating an environment which assists, or at least doesn’t hinder, personnel to perform at a high level. Behaviour is a powerful communicator. It doesn’t matter how much a company tells its operators how important they are. If their actions, as exhibited by indifference over the working environment, tell the opposite story, it is the latter which will carry more impact. In addition, the factors which motivate are often different to the factors that de-motivate personnel. Whilst good housekeeping in messing facilities may not inspire operators to greater performance, poor housekeeping will definitely de-motivate them.

<table>
<thead>
<tr>
<th></th>
<th>Risks Identified Pertaining to Operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Operators lack of understanding of specifications and standards</td>
</tr>
<tr>
<td>6</td>
<td>Operator attitude to work, client supervision and communication.</td>
</tr>
<tr>
<td>7</td>
<td>Quality of messing facilities available</td>
</tr>
</tbody>
</table>

Table 5 Risks Identified Pertaining to Operators

There are two main theories of motivation: Maslow’s Hierarchy of Needs (1954) and Herzberg’s Dual Factors (1966).

Maslow proposed a pyramid of needs with basic **physiological** needs (e.g. hunger, warmth etc) at the bottom and working up through **safety** (physical safety, job security etc), **affiliation** (social contacts, belonging, friends etc), **esteem** (both self esteem and recognition from others) and finally **self-actualisation** (self-fulfilment derived from achievement). As each level of need is satisfied the next level takes over as a motivator.

Herzberg’s work is compatible with Maslow’s theory. It is based on the fact that people are motivated towards what makes them feel good and away from what makes them feel bad. So factors such as achievement, recognition responsibility are positive motivational factors. So called Hygiene factors such as supervision, working conditions and security do not motivate but rather will cause dissatisfaction if they are not sufficient or adequate. One of the principles of Herzberg’s work is that the opposite of job satisfaction is not job dissatisfaction but no job satisfaction and likewise the opposite of job dissatisfaction is no job dissatisfaction.

In a lot of cases the companies had already taken mitigation actions against these risks and these are described in section 10.2 below.
9.3 Job Descriptions

Following the discussion at the Operator Workshop, it was clear that the operator role, particularly in the jobbing inspection environment, involved much more than just performing NDT. In addition the limits of the operator’s responsibility appeared to be blurred.

One way of clearly defining the operator’s responsibilities could be to state them in a job description which the operator had easy access to and could use as a guide when performing a job. The current use of job descriptions was investigated and found to differ across the industry.

Where they do exist, their purposes vary. Some job descriptions are written to meet QA or human resource requirements whilst others are incorporated into a competence system providing Suitably Qualified and Experienced Personnel (SQEP) job profiles and job requirements. This in turn leads to variability in detail with some descriptions being too general and brief to provide the operator with clear details about his role.

The operator role and responsibilities are communicated using alternative methods:

* Job specific worksheets or detailed work instructions are produced for each job, stating responsibilities and lines of management reporting.
* For operators hired as contractors, the requirements may be stipulated in the operator’s contract.
* Responsibilities may be established through training and company culture.

Whatever the communication medium, operators need to:

* Have defined boundaries of responsibility.
* Be clear regarding what is expected from them.
* Know how they fit into QA system.
* Have access to specified documentation.
* Understand how their role can be developed.
* Be trained in activities other than the application of NDT techniques.

10 Proposed Solutions

10.1 Safety Culture

Safety culture is important in the context of NDT reliability since it affects all aspects of the NDT process, from planning, to implementation, and the final treatment of results. NDT is often characterised as an activity that manufacturers and plant owners only do because they have to, and therefore NDT is seen as a burden on the resources of the company. This often means that NDT suffers from lack of funding and client support.

There are three typical stages in the development of a safety culture:

1. Safety is compliance driven and is based mainly on rules and regulations. At this stage, safety is seen as a technical issue, whereby compliance with externally imposed rules and regulations is considered adequate for safety. (This should be the minimum that industry works to rather than aspiring to achieve).
2. Good safety performance becomes an organisational goal and is dealt with primarily in terms of safety targets or goals.
3. Safety is seen as a continuing process of improvement to which everyone can contribute.

In the context of NDT, stage 1 refers to the attitude that inspection is only performed because it is required by codes and standards and regulations. This generally starts as a client / management attitude, but if this attitude is observed by the actual operators, then there is the danger that they will approach their work with a similar attitude. Studies of inspection reliability have concluded that one of the factors which affect the reliability of an inspection is the attitude
of the operator towards the inspection. If operators believe that they are only performing the inspection because it is just one of the things that has to be done in order to despatch a component or start a plant operating again, then they are likely to be less careful and the reliability is likely to be poor. If, however, an operator believes that the inspection which they are performing can affect the safety of the plant, with all of the consequences which that could involve, then they are likely to be more careful in the way they perform the inspection and interpret the results.

Stage 2 occurs when it is acknowledged that safety is important to the success of the business.

Stage 3 is the most desirable level since it indicates that the safety culture is well developed and that operating at a high level of safety is natural to everyone working on the plant. In the context of the NDT, a “Stage 3” culture would be demonstrated by the following examples:

- NDT operators are able (and encouraged) to report shortcomings in the application of the NDT.
- A “no-blame” atmosphere exists so that mistakes are not punished but are investigated openly to avoid repeating mistakes.
- NDT is given sufficient priority and the work of NDT personnel is valued and respected. This would enable NDT personnel to develop a pride in their work.
- Management activities for developing improvements to the NDT and the NDT process are undertaken.
- Near miss reporting is applied as a motivator / awareness tool so operators and organisations can learn from others’ experiences (learning organisation).

A large number of studies have been made of safety culture. References 7 and 8 provide further information.

10.2 Recommendations from Previously Reported Studies

The need and the steps required to minimise the effect of the environment (access, heat, noise etc) are well understood if not always acted on. The need for a suitable procedure and appropriate equipment and operator familiarisation with both has also been widely promoted. Validation / performance demonstration have been shown to benefit the reliability of inspections through operator practice with the procedure and inspection equipment and job specific training has been promoted and was shown to be of benefit in the PANI 2 project.

For manual ultrasonic inspection, the motor skill required to scan the probe correctly to ensure that the defect indication appears on the screen has been identified as a key factor which could lead to errors. PISC III [9] illustrated how this skill could be improved through specific training for the operator.

It is acknowledged that the application of manual ultrasonics and NDE in general is a vigilance task. Vigilance deteriorates with time and varies from person to person. Motivation of the operator will affect vigilance. A lot of research has been done on vigilance in general and ways of maintaining and improving it have been proposed:

- Frequent breaks.
- Team working.
- Organisational support.
- Introverts are known to perform better at vigilance tasks.

From the many studies that have been conducted on NDT reliability (as referenced in the Interim Report and in References 9 to 12 of this report), the various recommendations for improving the reliability of manual ultrasonics include:
Implementation

a) Operators should be briefed on the inspection and the history of the component prior to performing an inspection.
b) Procedures should be written to describe, in a clear and unambiguous way, the activities required for an inspection to achieve its objectives.
c) Guidelines for work area preparation should be established.
d) Checklists should be used to guide any decision making processes.
e) Plotting aids should be used when reporting results.
f) Plant operators should note and consider operator's fatigue when planning inspection programmes.
g) Steps should be taken to increase the motivation of the operators.
h) The operators should feel supported by the plant operators.
i) Inspections should be repeated by different operators.
j) Inspections should be audited.

Training

k) More hands-on and classroom training should be given using representative test pieces (specimens made of similar material and specimens with similar geometry to the actual component) with more feedback given to the operators on their performance.
l) Inspection simulators should be used for training and exams if possible.
m) Training programmes should emphasise the importance of scanning skills.
n) Job specific training should be given, covering the background, equipment and procedure (including reporting procedure).

Qualification

o) Inspections should be qualified.
p) Qualification Bodies should review the conditions (environmental and work pattern) in which qualifications are performed.

10.3 Experience from the USA

A lot of work has been performed in the USA on human reliability, particularly in the aerospace industry. A presentation was given at the 33rd Annual Review of Progress in Quantitative NDE, July 2006, by Matthew J. Golis entitled "The Major Role of Human Factors in Nondestructive Materials Evaluation". The presentation wasn't written up but the presenter provided information on the basis of the content [Ref. 13]:

Meetings were held with human effects professionals and experienced inspectors to see what might be done to improve the existing situation. The conclusions suggest that performance is based on numerous factors that vary from one inspection setting to the next. The outline of the major categories that were noted in no particular order were:

a) The human nature of the inspector (personality, motivation, physical condition, level of confidence)
b) Inspector training (general traditional NDT training, specific case orientations)
c) Adequacy of instructions (verified and valid procedures, awareness of inspection criticality)
d) Environment (physical as well as inter-personal both at home and the work place)
e) Equipment (complexity, readiness and inspector's familiarity with its use)
f) Management (attitudes regarding misses vs. false calls, process violations, production vs. safety)
g) Vigilance (looking but not seeing, anxiety and boredom, performance expectations)

If significant improvements are to be achieved, incremental changes in most of these categories need to be made because any one of them will probably not make that much difference.

The stated reasons for typical weaknesses in the inspection programs seem almost endless. e.g.
Inaccurate technical instructions.
No consistent policy or enforcement.
Production pressures.
Poor quality control.
Poor organizational support.
Having a bad day.
Under-skilled inspectors.
Under-motivated inspectors.
Worker turn-over.
Aging workforce.

Note that the majority of these reasons do not depend on the inspector!

The discussions led to the following possible strategies:

1. To improve inspection personnel:
   • Consider selection criteria based on personality characteristics such as patience, concentration, tolerance of external conditions, manual dexterity, and integrity.
   • Define personal goals in context of overall career, emphasize respect for performance, maintain a fair wage so low pay does not become a negative factor.
   • Build confidence through repeated performance demonstration and acknowledgement of successful performance.

2. To improve training:
   • Put premium on demonstrated practical hands-on training.
   • Conduct formal training when non-standard specific cases are encountered (don't "wing it").

3. To improve instructions:
   • Develop written instructions collaboratively with qualified engineers, experienced inspectors and possibly human effects personnel.
   • Verify the effectiveness of the instructions through a formal validation process.
   • Use a clear system to identify criticality of inspection when deemed necessary.

4. To improve environment:
   • Adjust work loads to avoid excessive fatigue (hours/physical positions) through rotation of personnel.
   • Reduce impact of temperature, humidity, noise, poor lighting and protective gear as much as possible.
   • Create a positive attitude toward co-workers based on mutual respect and performance.

5. To improve equipment:
   • Seek instrumentation that has the most simple and reliable interface with the inspector.
   • Allow time for inspectors to become thoroughly familiar with new equipment so they are confident in its performance and confident in their ability to make it do what must be done.

6. To improve management:
   • Recognize that management sets the tone of the inspection program and if their predisposition is toward production at the expense of the integrity of the inspection process, the results will never be optimum.

7. To improve vigilance:
   • This time-dependent effect is usually addressed by rotating inspection personnel so the task does not become routine and mind-deadening. Changing assignments and introducing fresh challenges renew the interests of the worker in most cases.
Tactics that have been used and considered effective include the following:

a) Whenever significant flaws are found, be sure that ALL inspection personnel have a chance to look them over and to see how their techniques would have fared in finding them. Take pictures and keep them available for review and subsequent training.

b) Use round-robin competitive exercises to measure how individuals and inspection teams are performing on contemporary test items. Share the results with all participants and shower the best performers with legitimate praise and recognition.

c) Conduct regular re-qualification performance demonstrations based on the finding of an assortment of flaws that are of interest to the organization. Repeatedly sitting for the same written-type tests does little to instil confidence that an inspector will do well on the job of finding flaws.

In the presenter’s opinion successful inspectors are special and rare. They need to be discovered through a selection process, cultivated through training and provision of the best of procedures and tools and continually reinforced through management support, peer recognition and performance demonstrations if their performance is to remain consistent and at a high level.

10.4 Industry Examples of Current Good Practice

As mentioned in Section 9.2, some of the companies who identified the risks to the manual ultrasonic process had already implemented mitigation in different ways.

With regard to the lack of information from the client, one company attempts to elicit the information from the client through the use of a questionnaire. Another company produces what is termed a “Site Bible”. This is produced before mobilisation and contains all standards, specifications, procedures, notifications, the reporting system and any forms that may be used on site. The client is given a copy, the operators keep a copy on site, and the main office keeps a copy. This ensures everyone knows what is being used and if there is the need to discuss or revise anything in the “Bible” then all parties have the relevant information. The use of the “Bible” does require that the information has to be obtained from the client for incorporation into it but the fact that all the necessary information is collected in one place can be a useful aide to highlighting any absences and their implications to the client.

The companies who identified this risk all allocated the ownership of the risk to the client. One way of ensuring that the client carries this risk, and minimising the impact to the NDT company, is to cover the issue in the terms and conditions of the contract. Although this does not address the underlying problem, by formally notifying the client that they will carry the risk there is a chance that they will want to mitigate it by providing the required information.

The risk of operator attitude adversely affecting the outcome of an inspection is mitigated by one company through the use of a full two way internal briefing. The company gives details on what is required whilst operators are expected to contribute through questions and stating whether they are confident on undertaking the job. Whilst this benefits the immediate job, it also assists in the identification of formal and / or on the job training requirements.

It is now a requirement of aviation regulations that personnel involved in the maintenance of aircraft are given training in human factors [Ref. 14]. The requirement is for initial training and recurrent training.

This training is required as part of a total system in managing human error, and discouraging procedural violations. Without proper training, other initiatives related to error management and safety improvement (such as error reporting and investigation, better shift and task handover procedures, improvements in procedure design, etc.) will probably not be effective in the long term.

Within the CAP 716 document [Ref. 14] the training is referred to as “human factors training” but it can also be described as “error management training”. The objectives of human factors training, are stated as:
• To improve safety.
• To decrease organisational exposure to risk.
• To reduce errors.
• To capture errors.

The aim of the training is intended to achieve these objectives by:
• Imparting knowledge on human factors and safety, and details of how the company human factors programme works.
• Developing skills (where appropriate).
• Influencing people’s attitudes.
• Influencing behaviour.

The CAP 716 document has many appendices giving guidance on related aspects. One of these appendices, Appendix O, gives information on “Visual Inspection and NDI”. Whilst the emphasis is on visual inspection there are some suggestions which could benefit the application of manual ultrasonics.

The inspection process is divided into: Initiate, Access, Search, Decision and Action. Table 2 of CAP 716 gives strategies for improving inspection which split into training for operators and system changes. The training proposed covers procedures, area location, search, decision and report writing skills. It is emphasised that training should always be supported by adequate experience. The system changes include calibration of equipment, feed forward training on expected flaws, better location of equipment during inspection, improved NDT templates, standards at the work point, pattern recognition job aids, feedback from practical experience to improve the inspection, improved fault marking and hands-free fault recording.

10.5 Other Ideas

Another initiative from the aerospace industry that was suggested by the training school (see the Interim Report in Appendix 2) as something that could be beneficial to all industries was to improve policing of the NDT process to ensure correct application. This was also separately proposed by the operational NDT unit (see the Interim Report in Appendix 2) and some NDT companies. In the aerospace industry, improvements have been made in this area by third party oversight with the NADCAP scheme.

As may be expected, the training school also suggested more time for training with different levels of syllabus whilst the NDT unit suggested a reduction in the re-qualification burden to reduce costs and demands on time. These two ideas may not be incompatible.

10.6 Summary

From the above, it is clear that there isn’t a single, simple solution to ensuring good manual ultrasonic inspections or good NDT in general. A concerted effort needs to be applied to providing the correct equipment, environment and support to enable the operator to do the best job possible. Based on the work in this report, the recommendations given in Section 12 have been derived. But in order to avoid these recommendations just being placed on the shelf with the recommendations from previous work, possible actions have been proposed and these were presented to the audience at the results seminar held at Risley on 25th July 2007.

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13 Training operators by imparting knowledge which can be used to predict an outcome based on existing information.
14 NADCAP – formerly National Aerospace and Defence Contractors Accreditation Program - a cooperative program of major companies designed to manage a cost-effective consensus approach to special processes & products and provide continual improvement within the aerospace & automotive industries – see http://www.pri-network.org/Nadcap/
10.6.1 Suggestions Presented to Results Seminar

The implementation of the PANI 3 recommendations could be achieved by the following developments:

1. Better Oversight of the Inspection Process

1a) An industry representative body such as the British Institute of NDT (BINDT) produces a Code of Conduct covering the application of NDT, which incorporates the information in the best practice guide with the more detailed human factors / operator issues raised by PANI 3.

1b) Inspection to be controlled by an organisation with a regulatory remit to undertake audits. This would work in the same way as the DoT operates the MOT scheme or building inspectors check on construction. (United Kingdom Accreditation Service (UKAS) or BINDT).

1c) Operator certification renewals to be governed by site audit of ticket holders, looking at how the operator performs within the overall process.

1d) It should be mandatory that all safety-related inspections are conducted by UKAS accredited companies.

2. Enhancing the Role of the Level 3, Level 2 and Chartered NDT Engineers

2a) The role of the level 3 in the in-service inspection (PCN) environment has been reduced in the main to that of signing off procedures. This should be brought back up to the level of responsibility of the American Society of Non-destructive Testing (ASNT) level 3 in a manufacturing environment.

2b) The training and qualification of the level 3 or Chartered NDT Engineer should be amended so that they can take responsibility for:

* Managing a pool of operators.
  * Specifying and monitoring on-going training.
  * Ensuring NDT staff are suitably qualified and experienced for the jobs they undertake.
* Managing inspections.
  * Ensuring full documentation is available.
  * Ensuring the inspection environment is suitable.
  * Managing human factors issues.
  * Briefing operators and providing technical support.
  * Liaising with the client to ensure that the items detailed in recommendation 4 are in place.

2c) The status of the PCN level 2 operators should be raised commensurate with the responsibility placed upon them and their results. Level 2 certificated ultrasonic test personnel should have the right to refuse to conduct or complete a test if, in their view, any one, or any combination of, the criteria below are not met. A system of arbitration should be established to deal with cases where there is disagreement between the contracting parties.

* All the hazards posed by the task have been considered in a risk assessment and have been addressed such that the risk is judged acceptable by the level 2 and that a safe system of work can be implemented to his satisfaction.
* All information judged necessary by the level 2 and level 3 about the inspection, the component and the defects to be detected and sized is available.
* There is a procedure and/or technique sheet for the test that is deemed to be both suitable and adequate by the level 3 and level 2.
* The level 2 considers himself or herself to be suitably trained, qualified and experienced to do the work (Note that the level 2 may only become aware that they are not suitably trained, qualified or experienced to do the work when they
commence the testing and find themselves unable to interpret the resultant indications).

- The level 2 has suitable equipment to do the work.
- The environmental conditions (temperature, weather, noise, etc) under which the work is to be done are acceptable to the level 2.
- The item is prepared for the test to a standard that is judged by the level 2 to meet the requirements of the inspection procedure.
- Sufficient time is allowed for the work to be completed, including reporting (and breaks, if thought necessary by the level 2).

Although the level 2 may consult others regarding indications observed, there must be no influence exerted to change the report of the test.

10.6.2 Outcome of the Discussion

The suggestion for a Code of Conduct was generally accepted. BINDT have taken a lead on this and produced an initial draft for discussion. A copy of this Code of Conduct is included in Appendix 10.

A lot of discussion centred around the NADCAP scheme and the possibility of adopting it for wider industry. It was pointed out that the scheme is an industry based initiative driven by quality demands rather than any regulatory pressure. The role of the level 3 is covered by the NADCAP scheme which makes specific reference to the inclusion of the level 3 in the whole quality process through a specific contract.

There were comments to say that the Level 3 input is required by legislation regarding the Pressure Equipment Directive (PED). However, whilst the UKAS Guidance on Accreditation for In-Service Inspection of Pressure Systems/Equipment [Ref. 15] refers to the level III approving training and examination and that companies should endeavour to use accredited NDT contractors, it offers alternatives of just using operators certified to a National scheme as long as they apply a documented procedure approved by a Level 3.

UKAS certify companies to an approved standard and a suggestion was made that a new standard should be produced.

The enhancements to the role of the Level 2 operator, whilst accepted in principle, raised the concern that these would effectively give operators carte blanche to do whatever they wanted. It was stressed that it is important to get information out to plant owners and that the PANI 3 results need to be publicised to a wider audience.

With so much information presented to the audience and with the wide implications of the proposed suggestions it is not surprising that the seminar was unable to arrive at an agreed course of action. However, it is hoped that with the development of the Code of Practice the profession can respond to the following conclusions and recommendations, reduce the variability in ultrasonic operator performance and hence improve both the reliability and standing of NDT.
11 Conclusions

1. The PANI 3 data revealed that operator performance on the test pieces was related to their scores on one of the ability measures and two of the personality scales measured in the project. Better operators’ performance was associated with higher scores on the test of Mechanical Comprehension and lower scores on the personality scales measuring Original Thinking and Cautiousness. The relationship between these ability and personality measures, and ultrasonic inspection performance was stronger than that found between ultrasonic inspection performance and the number of years of experience that an operator had in undertaking manual ultrasonic inspections.

2. The PANI 3 test pieces were challenging but the ultrasonic results obtained from the 40 operators, who participated, were similar to those observed in previous PANI and other round robin exercises:
   - All defects in the test pieces used in PANI 3 were detectable using the applied procedure.
   - All defects were detected by at least 40% of the operators who inspected for them.
   - Average detection frequencies for each test piece varied from 58% to 67%.
   - The average circumferential positioning error over all defects for each operator ranged from 0mm to 28mm.
   - The average length error was +1.3mm and the average standard deviation for operators reporting two of more defects was 12mm. The external circumference of the pipe was 688mm.
   - The number of false calls overall was 16 with 2 operators reporting 2 and no operators reporting a higher number.

3. In a theoretical examination, the operators in PANI 3 demonstrated a good understanding of the basic principles of ultrasonic inspection as used every time an inspection is done. Their comprehension and knowledge of important but less frequently used features of ultrasonic inspection was less good.

4. De-briefing the operators following their inspection of the test pieces revealed a number of important conclusions based on discriminating between closely located defect and geometric echoes:
   - The operators were easily able to describe why they had determined that certain signals were from geometrical features of the test piece rather than defects.
   - The operators were less able to explain why they had reported indications as arising from defects. Knowledge of how ultrasonics interacts with defects was not used to assist the decision-making process in many cases. Their reasoning processes were not well defined and they frequently came to a decision before all relevant information had been acquired.

5. Observation of the trials and analysis of video recordings highlighted that for the best performance, operators should be able to:
   - Understand the implications of the geometry for the inspection. This requires that operators be given training in the understanding of ultrasound/reflector interaction.
   - Apply the procedure in a systematic way. This requires that the procedure needs to be written in a way which specifies the decision making steps.
   It is worth noting that current certification arrangements are not dependent on operators being able to correctly characterise defects.

6. The output from the operator’s workshop showed that an operator’s ideal inspection process is one where:
   - The preparation for the inspection in terms of access, safety and plant surface condition is performed by the client or NDT organisation, as appropriate, in advance;
Suitable documentation including risk assessments, inspection procedures, standards, acceptance standards, access and cleaning requirements, drawings and photos and equipment inventory are provided;

Adequate time is allowed for the inspection. This allows the operator to concentrate simply on carrying out the inspection. The NDT organisation should ensure that the operator is aware of the extent of his responsibilities.

7. Feedback from contributors to the project indicated that an organisational culture can predominate in which inspection is regarded simply as a statutory or contractual necessity rather than as a valuable process which can help avoid plant failures. This can lead to problems with lack of information, inadequate preparation, poor access and working conditions, unreasonable time pressures and poor remuneration. Also, operators are aware of, and influenced by, the pressure to report a clean bill of health considering the costs and time delays to the operation of plant if a defect is found.

### 12 Recommendations

1. NDT organisations and operators should consider the use of ability and personality tests for:
   - Selecting new trainee ultrasonic operators.
   - Tailoring training courses to meet individual’s specific needs for development.
   - Developing procedures at a suitable level of detail to support operators when undertaking assessments.
   - Identifying skills that should be developed as part of ultrasonic operator initial and refresher training.

2. Where relevant to an operator’s role, his/her training should be expanded to include:
   - A better understanding of how ultrasound interacts with defects and how to use this knowledge.
   - A knowledge of how observed ultrasonic signals arise from different potential sources of reflection and how to make a characterisation decision based on this information.
   - A grounding in the preparation requirements regarding administration, documentation, equipment and site support needed as a basis for a successful inspection. These requirements must be met prior to going to site to carry out the work.
   - A clear awareness of the roles and responsibilities in the inspection process.

3. Inspection procedures should be written in a way which promotes their systematic application.

4. Apart from carrying out the inspection itself, the role of operators in an inspection should be limited to verifying the adequacy of the arrangements for safety, access and plant condition. The preparation for the inspection and the provision of an adequate and appropriate inspection procedure is the responsibility of the client and/or NDT organisation as appropriate.

5. All organisations should promote a culture in which NDT is valued as a key input to the safe and cost-effective operation of plant. Organisations must provide or facilitate the necessary preparation of and on-site facilities for inspection and in particular they must allow adequate time for the inspection to be completed safely, accurately and reliably. A Code of Conduct for Industrial Plant Owners has been proposed to assist in this process (see Appendix 10).
13 References


5. http://www.ase-solutions.co.uk/


13. Private Communication e-mail from M Golis to B McGrath, October 2006.


Appendix 1
PANI 3 Management Committee
Membership of the PANI 3 Committee

John Whittle  Chairman, Independent
Harry Bainbridge  HSE
Rick Gregory  Exxon Mobil
Engineering Europe Ltd
Roger Lyon  RWE Power International
Shaun Smalley  SCS International
Stewart Hewerdine  ABB Engineering Services
Fraser Hardie  Doosan Babcock Ltd
Robin Shipp  British Institute of NDT
Muny Baborovsky  Magnox Electric
Cameron Sinclair  Zurich Risk Services (SAFed)
John Rudlin  TWI
Phil Heyes  Health & Safety Laboratory
Ian Bradley  BP Exploration & Production Technology Group
Peter Campbell  Defence Procurement Agency
Peter Nolan  Advantica
Bernard McGrath  Serco Assurance
PANI 3 Management Committee

Terms of Reference

Scope

These Terms of Reference cover the activities of the PANI 3 Management Committee in the management of the PANI 3 project and are applicable for the duration of the project or as otherwise amended by the agreement of the committee.

Objectives

The objective of the PANI 3 project is to reduce the affect of human performance variability on the results of manual ultrasonics.

This is to be achieved by assessing relevant human factors issues so as to identify those factors which have the biggest influence on the performance of ultrasonic operators. These factors will then be used to develop solutions, which industry can implement to achieve greater reliability of manual ultrasonic inspection.

The objectives of the Management Committee are as follows:

1. To ensure that the PANI 3 project meets its objective.
2. To monitor the PANI 3 project and ensure that it is relevant to the needs of industry.
3. To ensure that there is good two way communication between the project and industry.
4. To ensure that the final report is a true representation of the results.
5. To ensure that the project conclusions and recommendations are supported by the results.
6. To ensure that the project results are promulgated throughout industry.
7. To support the acceptance of the results by industry.

Membership

The committee will be made up of an independent Chairperson, the HSE technical project manager, a secretary and representatives from relevant industry sectors as listed below – please note that some nominees cover more than one sector.

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<tr>
<th>Role</th>
<th>Current Nominee</th>
<th>Organisation</th>
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</thead>
<tbody>
<tr>
<td>Independent Chairperson</td>
<td>John Whittle</td>
<td>John Whittle Associates</td>
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<tr>
<td>HSE Technical Project Manager</td>
<td>Harry Bainbridge</td>
<td>HSE</td>
</tr>
<tr>
<td>Secretary / Project Manager</td>
<td>Bernard McGrath</td>
<td>Serco Assurance</td>
</tr>
<tr>
<td>Sector Representatives</td>
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<tr>
<td>BINDT</td>
<td>Robin Shipp</td>
<td>British Institute of NDT</td>
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<tr>
<td>Certification and Training Bodies</td>
<td>Robin Shipp</td>
<td>British Institute of NDT</td>
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<tr>
<td>Chemical</td>
<td>Stewart Hewerdine</td>
<td>ABB Engineering Services</td>
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<tr>
<td>Defence</td>
<td>Peter Campbell</td>
<td>DPA, MOD</td>
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<tr>
<td>Gas Transmission</td>
<td>Peter Nolan</td>
<td>Advantica</td>
</tr>
<tr>
<td>NDT Practitioners</td>
<td>Shaun Smalley</td>
<td>SCS Int.</td>
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<tr>
<td>Oil &amp; Gas Offshore</td>
<td>Ian Bradley</td>
<td>BP Exploration &amp; Production Technology Group</td>
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<tr>
<td>Oil &amp; Gas Onshore</td>
<td>Rick Gregory</td>
<td>ExxonMobil Engineering Europe Ltd</td>
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<tr>
<td>Original Equipment</td>
<td>Fraser Hardie</td>
<td>Doosan Babcock Ltd</td>
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<tr>
<td>Manufacturer</td>
<td>Generation (Conventional)</td>
<td>Roger Lyon</td>
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<td>Power</td>
<td>Muny Baborovsky</td>
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<td>Regulatory Bodies</td>
<td>Phil Heyes</td>
<td>Health &amp; Safety Laboratory</td>
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<td>SAFed</td>
<td>Cameron Sinclair</td>
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<td>Research and Applications</td>
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Any interested parties not covered by the above sectors can request representation through the secretary.

**Responsibilities**

The committee members are responsible for representing the interests of their industrial sector. This requires them to consult other interested parties within their sector and to ensure that the results and documents produced by the project are promulgated to those parties.

In the event that a committee member is unable to attend a meeting, the member must decide whether it is appropriate to send a substitute representative for the relevant sector.

**Quorum**

A quorum will be formed by 8 members one of whom must be the Chairman or the HSE Technical Project Manager.

**Principal Tasks**

The committee will formally review the PANI project work and ensure it is directed towards the agreed objectives of the project. The committee will endorse the acceptance or modification to any proposed work. Modifications shall be suggested and agreed in order to achieve the project goals.

The committee will agree the wording and publication of project reports.

**Operation**

The committee will operate on a basis of unanimity. In the event of failure to agree unanimously, the HSE Technical Project Manager and the Chairman shall propose a way forward that is acceptable to a majority of attendees.

The committee will meet as required in the project plan. The schedule of meetings can be altered by agreement of the committee as required by the project work.

**Agenda**

An agenda will be produced and distributed to members prior to each meeting.

**Minutes**

Formal minutes will be produced for all the meetings except where the meeting is solely devoted to the agreement of a report. In this case the minutes will be replaced by the updated draft of the report.

The minutes of a meeting will be formally agreed at the subsequent meeting.
Appendix 2

PANI 3 Interim Report

PANI 3 – Interim Report on Data Gathering Report to Health & Safety Executive
Executive Summary

The Health & Safety Executive initiated the Programme for the Assessment of NDT in Industry (PANI) with a view to establishing and improving the effectiveness of NDT as applied in general industry as opposed to that applied under the more stringent requirements of the nuclear industry. The objective of the current and third project, PANI 3, is to identify solutions which will allow industry to optimise performance and thus minimise the magnitude of the variation in operator performance illustrated by PANI 2.

The first phase of PANI 3 was to gather and review data on both the inspection process and relevant human factors research in order to inform and target the subsequent experimental work. This report presents and discusses the information obtained from the various data gathering activities: a literature search, a workshop to collect the views of operators and visits to an NDT training school and an operational NDT unit.

The information presented in the report supports the proposed experimental investigation into the decision making process and the proposed investigation into the correlation between the quality of the decisions and the performance in ability tests.

The following areas have been identified as areas where changes can be made to the inspection process in order to improve the reliability of manual ultrasonic inspection:

- Planning and preparation
- Safety
- Communication
- Management
- Training

It is recommended that both the QA and the experimental work proposed in Section 7 be undertaken.
## Contents

1. **Introduction**  
2. **Data Gathering Methodology**  
3. **Literature Review**  
   3.1 Introduction  
   3.2 Glossary  
   3.3 The Manual Ultrasonic Task  
   3.4 Operator Performance  
      3.4.1 The Inspection Environment  
      3.4.2 Training and Procedural Aspects  
   3.5 Current Situation  
      3.5.1 The NDT Task and Decision Making Strategies  
      3.5.2 The Conflicting Requirements of the NDT Task  
   3.6 Areas for Further Work  
4. **Operator Workshop**  
   4.1 Workshop Programme  
      4.1.1 Process Mapping  
      4.1.2 Individual Group Sessions  
   4.2 Workshop Output  
      4.2.1 Session 1: Operator's View Point of the Inspection Process  
      4.2.2 Session 2: Management and Client interactions with the outlined Operator's  
         Inspection Process  
      4.2.3 Session 3: Ideal Process  
   4.3 General Workshop Discussion  
5. **Visits**  
   5.1 Training School Visit  
      5.1.1 Format  
      5.1.2 Summary of Issues  
      5.1.3 Areas for Improvement  
   5.2 Engineering Workshop Visit  
      5.2.1 Format  
      5.2.2 Summary of Issues  
      5.2.3 Areas for Improvement  
      5.2.4 Ideal Operator  
6. **General Discussion**  
   6.1 The Organisation  
   6.2 Individual Aspects
7 Further Investigative Work 33

7.1 The NDT Process 33
7.2 Decision Making Process 33
7.3 Operator Ability 33
7.3.1 Consideration of Tests 33
7.4 Proposed Experimental Work 35
7.4.1 Objectives 35
7.4.2 How to Meet the Objective 35
7.4.3 Proposed Methodology 36
7.4.4 Timings 36
7.4.5 Test Piece & Theoretical Assessment Design 37
7.4.6 Conduct of Ability Tests 37
7.4.7 Recording of Decision Making Process 37

8 Conclusions & Recommendation 37

9 References 38

APPENDIX 1 OPERATOR WORKSHOP PROGRAMME
1 Introduction

In July 2005, the UK’s Health & Safety Executive (HSE) awarded the contract for the third project of the Programme for the Assessment of NDT in Industry (PANI). The first project, which has become known as PANI 1, investigated the application of manual ultrasonics to a number of test pieces containing realistic defects. The techniques used to inspect the test pieces were based on the requirements of the appropriate standards and the operators were qualified through the national certification scheme. The manufactured test pieces and defects were designed to be representative of those encountered during in-service operation of industrial plant.

The PANI 1 report [Ref. 1] concluded that “the application of a generic procedure, based on a national standard, using operators with a generic qualification will not necessarily provide good detection or sizing reliability, particularly on complex geometries.” This led to the recommendation: “Ways of improving the reliability of application of manual ultrasonics should be considered, particularly when non-simple geometries are to be inspected and the structurally important defects are of a similar size to those in the PANI test pieces.” The report went on to suggest ways of improvement which could be applied:

- Use of specific training and practice specimens
- Use of inspection aids for scanning and data recording
- Use of improved procedures and techniques tailored to the specific geometry and defects
- Use of multiple, independent inspections to reduce the effect of random human errors

The HSE then commissioned a second project, PANI 2, with the objective of investigating the methods for improving the reliability of NDT recommended by the PANI 1 report, and quantifying their benefits. This data was required to allow industry to make a cost benefit analysis for adopting the improvements and hopefully, where appropriate, would lead to improved reliability of inspections.

PANI 2 [Ref. 2] achieved its objective of quantifying the improvements in reliability of manual ultrasonic inspection that can be obtained by implementing simple steps such as a targeted procedure, job specific training and conducting two independent inspections. Three groups of operators carried out inspections of manufactured test pieces: one group, the control group, applied a standard based procedure; another group applied an improved or targeted procedure; the final group had training on a practice test piece before inspecting the full test piece.

The most striking feature of the PANI 2 results was the variation in performance within each of the group of operators. This variation swamps the difference in performance obtained between the three groups. Hence, any measures adopted by industry to improve reliability may be negated by an individual operator’s performance.

The PANI 2 results posed the challenge of how to reduce the variation in performance between nominally similar operators and ensure that they are all at the higher level of performance. It was difficult to identify any factor which explained the variation. A possible link was suggested by the fact that the flaw detection frequency (FDF) for those operators who applied ultrasonics daily was shown to be greater and, statistically, significantly different from the FDF of the operators who reported that they applied ultrasonics either more than once a month or more than once a year. However, the differences were too small to explain the very large variations in performance observed.

The PANI 3 project has been instigated with the objective of identifying solutions which will allow industry to optimise performance and minimise the magnitude of this operator variation. PANI 3 will do this through an investigation into operator decision making from a human factors view point combined with a detailed analysis of the inspection process.

The initial step is to gather and review all the data on human factors relevant to the project. This interim report presents and assesses this data and presents recommendations for the subsequent investigative work. Section 2 describes the data collection exercise and Section 3 presents the
literature review. Section 4 gives a report from an operator workshop which was held to obtain the views of NDT operators on the application of the NDT process. Section 5 describes the information obtained during visits to a training school and an operational NDT unit respectively. The data is discussed in Section 6. Section 7 suggests areas for further investigative work and presents a review of the cognitive and physical ability tests that could be used to measure the skills that underpin the tasks undertaken as part of NDT inspection. Conclusions and recommendations are given in Section 8.

2 Data Gathering Methodology

The magnitude of the variation in performance between operators illustrated in the PANI 2 results came as a surprise because there is a natural inclination to believe that advances in technology and changes in training and certification will have produced consequential improvements in operator performance. However, just a cursory glance at previous work highlights the fact that the PANI 2 results are very similar to those of earlier exercises and little headway has been made, over the years, in optimising performance and reducing operator performance variation.

Many of the studies which have reported operator variation have made recommendations on how to improve reliability. So the first step was to identify and review previous published work relevant to the reliability of manual ultrasonic inspection and to assess the conclusions and recommendations. This work has been undertaken by a Human Factors Consultant. Visits to a training school and an operational NDT unit were undertaken with the main objective of informing the Human Factors Consultant on the training and working environment of NDT operators. However, the opportunity was taken during these visits to examine the NDT processes and their impact.

A key source of data on what affects the performance of the operator is the actual operator. In previous exercises, questionnaires have been used to elicit information from operators. For PANI 3 an operator workshop was used as the vehicle to collect the views and opinions of operators from different backgrounds.

Finally, in preparation for the experimental work, the identification of appropriate ability tests has been completed.

3 Literature Review

3.1 Introduction

The consequences of a component not meeting its service requirement can be hazardous, if not catastrophic in some industries. As a result of this, In-Service Inspection (ISI) has been the focus of industrial attention for a number of decades. Non-Destructive Testing (NDT) is a primary recovery mechanism for errors in design, construction and operational activities and is often the last line of defence in the prevention of major incidents. With industrial demands driving the extension of plant life, the effectiveness of NDT is becoming increasingly important to the safety of plant operation. According to Dickens and Bray [Ref. 3], materials are being pushed to their limits in order to reduce weight and cost and designs are subject to service conditions beyond the original specifications. This process they refer to as “peak utilisation”.

There are a number of common NDT techniques including visual inspection, magnetic particle inspection, dye penetrant inspection and eddy current inspection for detecting surface breaking defects and radiography and ultrasonic testing for detecting defects throughout the full volume of the component. However, it is ultrasonic testing (UT) that has come under close scrutiny due to its importance in detecting and sizing defects of structural concern, its broad use across industries, and the reliance on the skill and performance of the operator.
### 3.2 Glossary

The human factors research described below refers to terms which are not commonly used outside of the human factors field. A description of the meanings of various phrases used in the following sections is presented here to aid understanding.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Ability</td>
<td>Possession of the necessary skill / competence to undertake particular tasks - used in a general sense e.g. numerical ability.</td>
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<tr>
<td>Abstract reasoning</td>
<td>To reach conclusions by considering a concept without thinking of a specific example.</td>
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<td>Aptitude</td>
<td>Similar to ability but more focussed on job specific requirements.</td>
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<tr>
<td>Behaviour</td>
<td>Any observable overt movement of the organism generally taken to include verbal behaviour as well as physical movements.</td>
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<tr>
<td>Cognition</td>
<td>All the mental activities associated with thinking, knowing, and remembering. The act, power or faculty of apprehending, knowing, or perceiving.</td>
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<tr>
<td>Cognitive Ability</td>
<td>The ability to observe and think clearly. The performance of the mental processes of comprehension, judgment, memory, and reasoning. Often split into distinct areas – spatial, numerical and verbal.</td>
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<tr>
<td>Cognitive Ability Tests</td>
<td>These tests are designed to measure a person's intelligence and mental ability. Some of the specific areas measured by cognitive ability tests include problem-solving, verbal ability, numerical ability, reasoning, memory, and general intelligence.</td>
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<tr>
<td>Context</td>
<td>The situation, circumstances or setting in which an event occurs.</td>
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<tr>
<td>Contextual factors</td>
<td>Factors which affect the situation or circumstances in which an event occurs.</td>
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<tr>
<td>Feedback training</td>
<td>Training operators by providing information on performance so that changes can be made to improve future performance.</td>
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<tr>
<td>Feedforward training</td>
<td>Training operators by imparting knowledge which can be used to predict an outcome based on existing information.</td>
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<tr>
<td>Human Factors</td>
<td>A multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to equipment, systems, facilities, procedures, jobs, environments, training, staffing, and personnel management for safe, comfortable, effective human performance.</td>
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<tr>
<td>Motivation</td>
<td>The process that acts, guides, and maintains behaviour.</td>
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<tr>
<td>Motivational factors</td>
<td>Factors which affect an individual’s motivation.</td>
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<tr>
<td>Risk</td>
<td>A subjective assessment made regarding the likelihood of achieving an objective within a specified time and with the resources provided.</td>
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<tr>
<td>Self-efficacy</td>
<td>A person’s belief that he or she can execute the behaviour necessary to control desired outcomes. The belief that one can achieve certain goals.</td>
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Spatial ability / spatial visualisation  The ability to visualise the position of objects in 2-D and 3-D space.

Vigilance  The process of paying close and continuous attention.

Please note that in the following sections, text in italics is quoted directly from the references given.

3.3  The Manual Ultrasonic Task

Manual UT is a task using simple technology, utilising the ability and experience of the operator, and is therefore considered to be one of the more cost effective methods of investigating the integrity of components in-service. Using a probe, couplant and an oscilloscope display, the operator must ascertain the presence or absence of defects in material and determine the size and location of those identified.

Over time, the equipment used by operators, i.e. digital or analogue flaw detectors and probes, has been improved but the basic principles remain unchanged. However, due to the nature of the task, the success of inspection is also subject to a complicated relationship between the equipment and operator skill.

The operator applies couplant to the surface to be assessed and, using the appropriate probe, systematically scans the area to be inspected whilst observing the signals produced by the material on the display used. The signals displayed to the operator require interpretation in order to determine whether they represent the presence of a defect or are a feature of the geometry of the component.

Harris [Ref. 4] described the principal signal characteristics, which provide the operator with information on the nature of the reflector, as follows:

- **Amplitude**  
The display-screen height of the signal from the display baseline, typically measured as a percentage.

- **Rise-time**  
The front slope of the signal, in terms of how rapidly or slowly it rises from the baseline to the signal peak.

- **Dynamics**  
The nature and extent of signal change that corresponds with linear or oscillatory movement of the transducer.

- **Peaks or facets**  
Signal shape made up of multiple peaks or peak-like elements along the signal slopes.

- **Location**  
(This is derived from the range of the signal and the beam angle).  
Whether or not the signal is from the vicinity of a known signal source (i.e. geometric feature), as determined from measurements made on an exterior surface of the component.

- **Continuity or persistence of a signal**  
The extent to which a signal is continuous or intermittent over an area of inspection.

- **Reference Comparison**  
Similarity of the characteristics of a signal with those of a signal from a known reference, such as a notch in a calibration block or known geometric source in the material inspected.

The process of UT requires the operator to perform an intricate and controlled spatial task in parallel with the complexities of a signal detection and analysis task. For a successful inspection, the designated area must be methodically and adequately covered by the probe to ensure that no defects have been missed, yet this must be completed whilst the operator maintains focus on the display to ensure that all significant signals are detected and correctly interpreted.
3.4 Operator Performance

Operator performance in trials is generally measured by Flaw Detection Frequency (FDF: the number of defects detected as a fraction or percentage of the number of defects inspected) or by establishing the probability of detecting defects that are present along with the probability of reporting defects that are not present (false reports).

The recognised standards for operator performance are considered to be a defect detection rate of 80 percent or higher with a defect false report rate of 20 percent [Ref. 4] (this latter figure is derived from the probability of false calls established during trials). However, in work done on the inspection of Inter-Granular Stress Corrosion Cracking (IGSCC), it was shown that operators can achieve this level of performance in training but that this was not necessarily echoed in practice [Ref. 5].

3.4.1 The Inspection Environment

As it is primarily a signal detection task, UT requires the operator to be vigilant, i.e. to concentrate on the flaw detector screen, which is affected by operator fatigue and motivation. Murgatroyd, Worrall, & Crutzen, [Ref. 6] measured Flaw Detection Frequency (FDF) and compared the capability of operators between laboratory-type conditions and the simulated industrial environment. The study also applied psychological monitoring of operator attitudes and assessed the physical and mental conditions of the operators.

The results indicated substantial differences in detection capability from day to day. However; these were considered to be due mainly to scanning skills, or loss of attention, as opposed to operator capability. This suggests that those issues generally associated with vigilance tasks, such as boredom, fatigue and motivation will clearly be present in UT.

In practice, UT is often performed under “highly stressful” conditions which include high temperature and humidity, poor lighting and high noise levels, poor access and difficult workspaces, extensive shifts, time pressures, and exposure to factors such as extreme weather conditions and radiation. Dickens and Bray [Ref. 3] suggest that as a task becomes increasingly more complex, environmental factors degrade performance.

As a result of this, research has historically investigated the more tangible elements of “Human Factors” of UT in industry, by assessing the conditions operators are subjected to when in the field. For example, in recent years, the international PISC programme has investigated various aspects of NDT when applied to the nuclear industry which include those related to the task and environmental conditions of UT. Recommendations have been made on both the management and regulation of inspection conditions and the consideration of operator selection based on physical characteristics [Ref. 6].

The working conditions described above are certainly less than ideal, and where practicable it is clear that appropriate steps should be taken to minimise both the risk to the operator and the potential for human error. Management clearly have a responsibility to provide a safe working environment for the completion of NDT. It is often the case that the responsibility of providing the appropriate equipment and working arrangements (such as rest-breaks, personal protective equipment etc.) with which to minimise both injury and error, falls on the operator.

However, although the conditions associated with in-service inspection should be managed and, where possible, optimised, these conditions must be endured to some degree in order to complete the work. As research has progressed, the majority of studies completed are conducted under controlled conditions such as laboratory or ‘mock’ industrial environments, which show that even when these extreme conditions are removed or minimised, considerable variation in operator performance remains.

As a result of these findings, it was clear that the problems associated with operator reliability are more complex than originally thought. Research was therefore directed towards the less tangible or
“softer” aspects of human factors which relate to the training of personnel and the procedural aspects of the task.

3.4.2 Training and Procedural Aspects

Behravesh, Karimi and Ford [Ref. 5] stated that despite efforts focussing on improved equipment, training and qualification, two problems remained:

- There was a relatively low pass rate on the qualification exams among workers who attended Electric Power Research Institute (EPRI) Non-Destructive Evaluation Centre’s Intergranular Stress Corrosion Cracking (IGSCC) detection course.
- Of those who did qualify, there was an apparent disparity between their good performance in training and poor field results. (It is not reported how the poor field results were established but it can only be assumed that defects were detected after operators had not reported their presence).

The approach used in this work was designed to identify the relevant “person” and “environment” variables that influence performance. The authors conducted two studies, the first focussing on the global traits of the workers and the problem of personnel selection, and the second focussing on specific episodes of work performance and the problems of training and management practices.

The results from Study 1 [Ref. 5], revealed that there are 7 clusters of attributes most commonly associated with effective performance, the most common of which include, conscientiousness, stress-tolerance, knowledge and self-efficacy. The results from Study 2, revealed that the contextual factors considered to be the highest contributors to good or poor performance include preplanning, managerial and supervisory cooperation and support, and efficient organisation. Behravesh, Karimi and Ford interpret these results as a suggestion that contextual factors are the major determinants of the outcome of performance, and that if operators have the basic skills required, then these factors can be offered as guidelines for management and training practices and selection of personnel.

However, it is clear from the majority of research presented here that the problems associated with UT are not this straightforward. Merely possessing the basic skills to perform the task coupled with appropriate management, training and selection, is not necessarily sufficient to produce reliably successful inspection. For example, the Programme for the Assessment of NDT in Industry (PANI) [Ref. 1] attempted to investigate the reasons behind the significant variations found in operator reliability in 1999. The PANI project took a snapshot of in-service NDT in the non-nuclear industry using 20 operators in a round robin exercise. The PANI investigation concluded that:

“The application of a generic procedure, based on a national standard, using operators with a generic qualification will not necessarily provide good detection or sizing reliability, particularly on complex geometries”

The results of PANI revealed that inspections can be unreliable in detecting defects and suggested the following ways in which reliability could be improved:

- The use of specific training and practice specimens.
- The use of inspection aids for scanning and data recording.
- The use of improved procedures and techniques tailored to the specific geometry and defects.
- The use of multiple, independent inspections to reduce the effect of random human errors.

PANI 2 [Ref. 2], a follow on project from the original PANI, was designed to investigate these methods of improvement and to quantify their benefits.

Operators were divided into 3 groups: the control group, the group provided with a detailed inspection procedure (described as an ‘improved’ procedure) and a third group which applied the same standard procedure as the control group but were given training and feedback on a practice specimen containing similar defects. The trials were conducted in a ‘mock’ industrial environment in an attempt to replicate some of the environmental conditions experienced by the operators.
This study highlighted striking variations in performance within each group, with FDF ranging from 30% to 80%. The group applying the improved procedure performed slightly better overall than the trained group, who, in turn, performed slightly better than the control group. Statistically, however, although there was a difference between the control group and the other two groups, there was no difference between the improved procedure and the trained group.

The influence on performance of qualification, age, experience, and frequency of use of UT were also investigated. However, no significant differences were identified.

The PANI 2 project concluded that the variation in detection frequency was difficult to explain and that future research should investigate the following:

- How can the operator’s skills be assessed and developed?
- What are the critical skills?
- What are the characteristics of a “good” operator?
- What is the best way of informing the operator about the inspection requirements?

The project therefore suggests that the focus of attention should shift towards the cognitive elements of UT such as operator skill and ability, and there are a number of studies which support this concept. For example, Harris [Ref. 4] addressed the reasons for unsatisfactory performance in ultrasonic inspections by completing a detailed examination of the inspection process employed to identify factors that influence inspection capability.

Using performance measures and tape-recorded commentary in a controlled performance-testing facility, Harris identified 9 information processing factors which correlated individually and collectively with inspection performance. Of the 9 factors identified, the presence of the following 4 factors was particularly powerful:

- Develop and test explicit hypotheses as an integral part of the inspection process.
- Avoid reaching a conclusion early in the inspection process, before all available information has been obtained and considered.
- Apply knowledge during the inspection by putting it in the form of IF-THEN logic.
- Avoid the arbitrary or inadvertent elimination of information from consideration during the process of reaching the inspection conclusion (disregard of evidence).

Harris believes that a successful inspection is more likely when an operator implements a well defined strategy for determining when a signal originates from a defect, as the presence of these four factors alone resulted in a 400% increase in the success rate of inspections compared to when they were not present. Again, these results were obtained from a controlled environment within a testing facility and have not been tested in field inspections.

According to Drury and Prabhu [Ref. 7], the operator applying an inspection operates on two distinct intellectual levels: a simple signal detection level when looking for signals on the flaw detector screen and a higher, more complex, level when choosing and modifying search patterns and when modifying their working practices in the light of experience. This ability to adapt and to work at two distinct levels makes the operator flexible and efficient at performing tasks but leaves them more prone to error.

Harris [Ref. 8] describes the application of NDT techniques as requiring the combined aptitudes of general cognitive ability, abstract reasoning and spatial visualisation and developed a tool for predicting the potential NDT performance of candidates selected for NDT jobs. The Dynamic Inspection Aptitude Test (DIAT) is a computer-based test designed to measure the requisite combination of aptitudes in performing a series of inspection-like tasks. The DIAT was shown to be highly reliable in predicting the qualification of operators, but no data is available regarding performance under field conditions.

Similarly, Enkvist, Edland and Svenson [Ref. 9] aimed to improve operator performance by exploring the operator’s decision strategies and the underlying factors which make some operators more successful than others. They used ability tests to test spatial ability and to predict operator capability but found no direct relationship between ultrasonic performance and the outcome of the
ability tests performed. However, this study found a link between motivational and contextual factors in that 55% of the variation of performance was explained by a “confidence” or “positive attitude”.

3.5 Current Situation

It would appear to be the case, from the studies discussed above, that both the motivational and contextual factors associated with inspection tasks, play a significant role in inspection performance. In addition to this, there is also considerable support for the claim that specific information processing activities must be applied in order to obtain successful inspections. It would seem that there is some importance in the decision making strategy adopted by the operator and the conditions under which those decisions are made, for example in the operator attitude towards their work, confidence in the decisions and organisational support provided.

3.5.1 The NDT Task and Decision Making Strategies

Wickens [Ref. 10] describes the decision making process as “sampling and integrating information in an attempt to formulate a hypothesis about the true state of the world”. He describes this hypothesizing process as involving interplay between long-term memory, where plausible hypotheses have been stored, and working memory, where alternative hypotheses are entertained, compared and evaluated. The outcome of this process, diagnosis, is often not absolute, but a degree of belief that one hypothesis is true. This is usually followed by a choice of actions and it is this choice which could be the significant factor when assessing the behaviour of NDT operators. Choice usually involves the evaluation of risk, particularly when there is uncertainty which will affect the consequence of the choice. Wickens describes two types of decision making, risky, leading to a course of action based on insufficient information, and conservative, those preferring to adopt caution when a decision is warranted. In addition to this, an important element of an information-processing model is feedback, in the sense that the outcome of the decision might affect future decisions.

With these elements in mind, consideration of the NDT task and the nature of the decision making process, produces three key issues:

1. The NDT environment is at best, problematic. Operators are frequently required to work in less than optimal conditions, with restricted access, heat, humidity, extreme weather, poor lighting and poor posture. Often these conditions are required to be endured for significant periods of time such as 8-12 hour shifts.

2. The task itself, although characteristic of a vigilance task, requires excellent spatial dexterity skills, in parallel with signal detection and interpretation capabilities. The combination of all three of these complex requirements simultaneously is likely to result in a significant strain on cognitive resources.

3. In addition to enduring the conditions and completing three complex tasks simultaneously, the operator is required to assume decision making skills which are often negatively affected by limits in attention and cognitive resources.

These three factors appear to contribute to both the unreliability and variability of NDT operators and the difficulty in providing assurance through in-service inspection of component integrity. However, in performing the literature review and investigating the NDT task through discussions with operators, managers and trainers, the Human Factors Consultant on the project has identified an additional factor which has the potential to play a significant role in the problems discussed above:

There are incompatibilities between the personality traits required in an inspector for different aspects of his work. The careful, methodical approach needed for safety-related requirements such as accuracy and complete coverage is at odds with the more pragmatic approach needed to cope with the practical problems such as restricted time and access and commercial pressures.
This is discussed in the next section.

3.5.2 The Conflicting Requirements of the NDT Task
The selection and training of operators requires those individuals with good signal detection capabilities and vigilance skills. These trainees are required to obtain the appropriate qualifications in detecting defects, calibration, development of procedures etc., and are assessed by what characteristics are believed to make a ‘good’ operator. Unfortunately, the concept of what makes a ‘good’ operator in training and certification is possibly far removed from the characteristics which result in a ‘good’ operator in practice.

This dichotomy derives from the inherent safety role of the task conflicting with the commercial view of undertaking the task. Industry requests NDT work to be completed, both as a requirement to justify plant safety and operation and to provide some assurance of plant status, and employs fully qualified and experienced operators. However, an attitude present in industry towards the performance of NDT and its consequences at the organisational level is a cause for concern. Aside from the cost of NDT alone, the cost and time delays associated with the detection of defects is a significant issue to the organisation, which results in the detection of defects becoming undesirable and unwanted. NDT operators are perfectly aware of this mind-set and if this factor alone is considered to be a form of feedback, clearly the effect on the operator’s decision making process will be detrimental.

The conflict itself appears to be between the type of decision making process the operator adopts. For example, NDT in general requires a conservative approach, particularly with regard to the safety and reliability of high risk plant, as risk taking (in the form of taking a course of action based on insufficient information) has the potential to result in disastrous consequences. However, the nature of the work, the time pressures, the conditions and the organisational response to the results, could be more likely to encourage a risky approach in operators, or result in operators adjusting decision making strategies in an attempt to achieve the required result.

The organisational pressures associated with NDT, for example the pressure to complete inspections as quickly as possible, the responsibility associated with detecting and reporting defects, the low pay and long hours and the continual pressures associated with qualification and training have the potential to cause the operator undue stress. Furthermore, it appears that operators are often not protected from the pressures of performing a key decision making role within an organisation or supported in their decisions, which results in an awareness of the consequences of every decision made. In addition, as discussed earlier, Dickens and Bray (1994) refer to the “peak utilization” of materials which inevitably place greater responsibility on the NDT operators.

These conditions create an environment which fosters low motivation, low job satisfaction, low operator confidence and negative attitudes towards both the organisation and the job itself. The performance of a safety related role, with decision making responsibilities, undue organisational pressure and low morale is unlikely to create an optimal environment for high reliability and continued success, particularly in relation to a task which is highly susceptible to stress and appears to demand high levels of motivation and a positive attitude.

There is also a question regarding the suitability of NDT training with respect to the implications for the reliability of UT. Firstly, there is the possibility that the training provided for NDT is purely functional in the sense that operators are trained according to the prescribed syllabus, in order to produce qualified operators. This, in theory, is not a problem until the qualified operator is required to apply the knowledge and abilities adopted through training to an unfamiliar task or environment. It is possible that current NDT training is not focussing on the aspects highlighted here, for example, planning and decision making, reporting and stress management. The result of this being that operators are qualified, but are not practically prepared for the role of applying their NDT knowledge in new and different environments.
It has been reported through discussions with NDT operators that there are additional stresses often experienced when attempting to complete NDT inspections. It seems that operators are often required not only to complete the inspection and provide a report, but often to plan the inspection, write the inspection procedure selecting the appropriate equipment and technique and prepare for the inspection. These situations result from a lack of client awareness of NDT requirements and best practice and simply add to the list of pressures associated with the completion of NDT in the field.

This point highlights the findings presented earlier from Behravesh, Karimi and Ford [Ref. 5], which discuss the importance of organisational support and pre-planning in the successful completion of NDT.

3.6 Areas for Further Work

The literature shows that the underlying factors concerning the unreliability of manual ultrasonic inspection are features of an extremely complex phenomenon. This unreliability has been shown not to be the product of one single factor but due to a combination of inter-related factors associated with the job, the individual and the organisation. This is consistent with the Health and Safety Executive’s (HSE) model of human factors which describes the need to optimise factors from all three of these areas in order to minimise human error and positively affect task performance [Ref. 11].

With respect to the ‘job’, the following aspects should be considered;
- the nature of the work including the physical characteristics
- the workplace and working environment
- the information and decision making requirements
- the perception of risk

When addressing the ‘individual’ aspects of behaviour at work, attention should be focussed on;
- personal attitude
- skills
- habits
- personalities

These aspects can affect task performance and be strengths or weaknesses depending on the task demands.

Finally the ‘organisation’ can often be overlooked during investigation, but can have the greatest influence on individual and group behaviour, and includes such factors as;
- planning
- safety
- communication
- management
- culture

It seems evident from the research reviewed here, that there are aspects of each of these factors which have been neglected during the investigations conducted into the unreliability of UT. It is accepted that research cannot effectively focus on the study of the complete UT environment. However, in order to produce practical solutions for industry, it is important that the significant contributors to poor performance in the field are identified.

On the basis of the literature review, it is recommended that work be performed on those factors considered to be of greater importance for further investigation and those which, for a variety of reasons, have not been addressed by research completed to date. These are:
- The organisation and organisational support for NDT (including the type and nature of the industry). The work should look at the level of support given to NDT operators to assist them in the task and to minimise the effect of potentially negative factors.
- The individual aspects of NDT such as the attitudes, the characteristics of the operators and the skills acquired. Such work offers the potential for selecting future
operators and identifying training and development needs of current operators. It will also assist in identifying the different levels of organisational support required for individuals.

- **The decision making process (including perception of risk).** This has been shown to be a key area in the success of inspections, particularly when dealing with complex signals. Analysis of the decision making process offers the potential for improving procedures, organisational support and operator training to ensure a successful inspection is achieved.

## 4 Operator Workshop

Although PANI 1 and PANI 2 have elicited information from the operators who have participated, the views of operators have not necessarily been given the prominence that they deserve. In PANI 3, this situation was rectified and a one day workshop was held to obtain input from operators.

### 4.1 Workshop Programme

Fifteen operators were hired to participate in the workshop. The operators came from a variety of organisations ranging from the NDT department of a large organisation to self employed operators obtained through an agency. All the operators held PCN Level 2 in ultrasonics but they had a variety of experience ranging from a relatively newly qualified operator with plate and pipe certification through to operators with nozzles and node certification and many years experience.

The programme for the workshop is given in Appendix 1. After an initial introduction to the HSE’s objective with respect to the overall project, a description of the different stages of the PANI projects and the purpose of the workshop, the operators were given an explanation of process mapping by a Quality Assurance Consultant.

### 4.1.1 Process Mapping

Process mapping was used to establish how NDT is currently managed and applied. It was then used to identify areas for improvement. Process mapping is a powerful tool in such applications. In its basic form it allows the sequential steps in a process and the required inputs and outputs to be identified and presented diagrammatically as shown in Figure 1. The resources necessary for each step and the interfaces with other parties can then be established as shown in Figure 2. In this figure, which is referred to as a deployment flowchart, the team members are listed across the top and task flow is plotted against this axis. Having established a current process, it is then possible to critically examine each step in the context of the whole process and identify where improvements can be made to achieve an improved process.

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1 PCN is the UK’s National, central certification scheme for NDT operators.
4.1.2 Individual Group Sessions

The operators were divided into 3 groups of 5 operators. Initially, each group was asked to map the process they currently apply. However, the operators identified three separate processes which are applied depending on the nature of the organisation, the employment contract and type of work. These were:

1. Individual, short term jobs in a variety of industry sectors.
2. A long term position providing NDT for a single organisation.
3. A medium term contract of a number of months providing NDT for a plant outage.

One group was then assigned to each of the above processes and asked to map it from instigation through to reporting. Each group performed their assigned task independently in a break out session. On completion of the session the groups came back together and reported to the whole workshop. The second breakout session was then used to identify the interfaces in the current
process. In the final session the operators were asked to map out what they thought would be the ideal process for the particular work situation. The workshop was closed with a final discussion on other factors which may impact on the operators’ performance.

4.2 Workshop Output

4.2.1 Session 1: Operator’s View Point of the Inspection Process

Team 1: Jobbing NDT Inspections

![Diagram of Jobbing Inspection Process]

**Figure 3 Map of Jobbing Inspection Process**

The process described by Team 1 is shown in Figure 3. The operator receives an instruction from his NDT service company to go to a site to perform an inspection. This instruction may or may not be suggested.
specify a procedure to use. Once at the site the operator has to liaise with the site contact, who may be elsewhere, to agree the requirements for the inspection. The operator may be required to specify the access and preparation requirements and even in some instances perform the preparation himself. The acceptance criteria for indications or defects will often be agreed at this point. The operator may receive some advice on the procedure to use but often it is down to the operator to decide the procedure and to recommend the acceptance levels for indications or defects. The operator then performs the inspection at the required sensitivity. This may differ from the sensitivity subsequently used in any audit inspection.

The probe calibrations will often be stored in the flaw detector and just recalled. The reporting of the inspection varies depending on the particular inspection. A verbal report will be given to the client. Defect indications may be marked up on the component and an interim hand written report produced. It is a common practice for the operator to assume that any obvious geometric restrictions to test such as the presence of a nozzle are known about by the client and so in this case the report will state “100% coverage where accessible”. A final report is issued by the NDT service company.

**Team 2: Production Environment using permanent NDT personnel or Long Term Contractors**

The process described by Team 2 is shown in Figure 4.

This process is more straightforward from the operators’ point of view than that encountered with jobbing inspections. The relationship between the NDT function and the client is well established and so proper preparation is performed prior to the inspection. Previous inspection history may be available to assist the operator and, whilst access, surface preparation and safety issues still need to be assessed by the operator, it is likely that these will have been addressed by other relevant parties. Reports are prepared and fed into the established client process.
Figure 4 Map of NDT Process When Using Permanent Personnel or Long Term Contractors
Team 3: Outage Environment, 4 to 6 week contract

The process described by Team 3 is shown in Figure 5.

![Diagram of NDT Process in Outage Environment]

**Figure 5 Map of NDT Process in Outage Environment**

This process falls in between the previous two processes with regard to the assistance the operator is given. However, there is still a lot of preparation for the operator to undertake before he actually performs the inspection.
Key Points from Group Session 1
A substantial part of the inspection process is actually preparation. Assistance from the company tends to be reactive rather than proactive. One item which stood out was the lack of any reference to Level III. Individual jobs rely a lot on the operator’s experience – selection of procedure, acceptance criteria, safety.

4.2.2 Session 2: Management and Client interactions with the outlined Operator’s Inspection Process
Having established the processes, the operators at the workshop then superimposed the interactions with their own management and the client. These are given below.

Team 1: Jobbing NDT Inspections

![Diagram of Jobbing Inspection Process Showing Interactions]

Figure 6 Jobbing Inspection Process Showing Interactions
Figure 6 shows the interactions for a typical jobbing inspection. The operator will be given instructions to go to site from his management. He will generally then personally contact the client to confirm arrangements. As described earlier, the site contact is not always present when the operator turns up on-site and so the onus for ensuring correct preparation falls on the operator. The specification for the inspection, the procedure to use and the appropriate acceptance standards are often not available or only provided in outline and it falls upon the operator to decide on the appropriate action. In an exception he may call upon his management to provide assistance. In selecting the procedure and the acceptance standard as well as when performing the inspection, the operator is under commercial pressure from the client to get the job finished and to pass the component as fit for purpose. There may be 3rd party involvement during the inspection.

The operator will provide a report to the client. The NDT company specify the format of the report, perform a technical review and have an ultimate sanction over the final issue of the report. In instances where defects have been detected and subsequently repaired, the client will often require that the final report just states the findings of the post repair inspection i.e. no defects found. When this occurs, the NDT service company often keeps copies of the interim reports with details of the defects found. The final report is archived by the NDT service company.

Finally, feedback from the client, whether good or bad is fed direct to the NDT service company. The interest shown by the NDT service company in feedback mainly comes from a repeat business view point rather than looking at operator performance.

Team 2: Production Environment using permanent NDT personnel or Long Term Contractors

The interactions for an operator performing inspections as a permanent employee or long term contractor to a client are shown in Figure 7. The initial information regarding the inspection is provided to the operator by his own management or supervisor. There is no need at this stage for the operator to have interaction with the client. The operator then assesses the job. If there are problems with issues such as surface preparation or access, then the operator will raise these with the client’s local supervisor. If these are not resolved then the operator can get support from his own supervisor. During the inspection the operator has no interaction with the client and has the ability to call on support from his own supervisor regarding problems such as equipment malfunction. The operator provides his own supervisor with verbal and written reports and has no interaction with the client. The operator’s supervisor gives the client the inspection reports.

Team 3: Outage Environment, 4 to 6 week contract

The interactions for an operator performing inspections on an outage or a 4 to 6 week contract client are shown in Figure 8. As with Team 2, the operator is not involved in the initial discussions with the client. The operator’s manager or supervisor then provides the operator with the support listed, allowing the operator to make his own preparations. On-site the operator has little contact with his own management and liaises directly with the client regarding the scheduling, the provision of services, safety and finally the reporting.
Figure 7 NDT Process When Using Permanent Personnel or Long Term Contractors Showing Interactions
4.2.3 Session 3: Ideal Process

In the final session the operators mapped the ideal process for their particular inspection scenario. They were also asked to identify any other factors which they considered would assist them in their job. These factors are discussed in Section 4.3 below.

Team 1: Jobbing NDT Inspections

As may have been expected in the light of the existing process identified by team 1 above, the ideal process for jobbing inspections removes some of the activities currently incumbent on the operator. So the initial enquiry discussion between the management of the NDT service company and the client results in an outline specification. The management then consult with the client to ensure that proper preparation for the inspection is performed. It was suggested that this
consultation should include digital photographs of the component to be tested so as to avoid any nasty surprises when the operator gets to site. The management then mobilise the operator passing on all the relevant information. The operator is therefore not required to have contact with the client until he arrives at site. On arrival at site the operator undertakes the necessary site inductions, performs the inspection and presents a hand written report to the client. The management review, approve and issue the final report to the client.

![Diagram of the Ideal Jobbing Inspection Process]

**Figure 9 Ideal Jobbing Inspection Process**

**Team 2: Production Environment using permanent NDT personnel or Long Term Contractors**

Team 2 didn’t produce an ideal process because they considered that the current process shown in Figure 4 was a good representation of the ideal process. However, they did have opinions on how their job could be improved and these are presented in Section 4.3.
Team 3: Outage Environment, 4 to 6 week contract

The ideal process for inspection during an outage is given in Figure 10 and Figure 11. This presents, in more detail, the process described for the permanent / long term contract process given in Figure 4. In agreement with Teams 1 and 2 the initial preparation is completed by the management and the client. The operator then works first with his management and then with the client to finish the necessary preparations. Good communication between the operator and the client and management are considered essential. The operator performs the inspection and writes a report which is passed to his own management / supervisor. The client receives the report from the management and not direct from the operator.

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Figure 10 Part 1 of 2 of Ideal Outage / 4 to 6 week contract Inspection Process
4.3 General Workshop Discussion

On completion of the process mapping exercises, a general discussion was held with all the operators to identify other factors which may assist them in the performance of their job. Additional comments were submitted by operators after the workshop. The views of the operators are summarised below:

*Time was a key issue. Adequate time to set up and to perform the inspection is considered necessary. It was stated that piece work gives the most audit failures. Ultrasonic examination is usually one of the last operations before returning plant to service, which can result in pressure on the technician to complete the inspection too quickly. During an outage period in petro chem and power industries, to comply with EU legislation, the normal working hours are up to 12 hours / day*
with 13 days on and 1 day off. Any exceptions to this have to be approved in advance where possible. It is believed that these work patterns are bad for technicians, doing a job that requires a high level of concentration. However, the technicians favour these long hours because they need as many hours work as possible in this period. They can be laid off for long periods during the rest of the year.

Associated with time is monetary pressure. Less monetary pressure should be put on the operators. Pay needs to be increased. It was suggested that inspections should be a Government concern and therefore be subsidised and that there should be a standardisation of company charge out rates.

Authors’ note: Whilst the latter suggestion may be against competition rules, there is a case, in the view of the qualifications and associated QA required by inspection companies, for a minimum charge out rate.

Training was also an issue. Both on the job and on going training were required, the former requiring sufficient time to be allocated to both the trainer and the trainee. Operators can be expected to give training to less experienced operators whilst performing inspections without being given any extra resources.

Better innovation of equipment is required. It was the operators’ opinion that old equipment is better than new. Technician input is required into equipment design.

A lot of companies buy couplant in powder form to be mixed with water prior to use. This can lead to the use of couplant with consistency too runny or too thick.

Information and preparation are both key to a good inspection. All were agreed that a greater client awareness of NDT is required.

It was suggested that solo operator working should be stopped: working with a Buddy was believed to improve safety and also improve productivity.

5 Visits

The project team, made up of the Human Factors Consultant, the QA Consultant and the project manager, visited an NDT training school and an operational NDT unit. The main objective of these visits was to observe the NDT training and working environment so as to be better able to assess the information obtained from the literature review and the process mapping. However, the opportunity was taken during these visits to examine the NDT processes in more detail. The results of the visits are described below.

5.1 Training School Visit

5.1.1 Format
The project team met with the Managing Director of an NDT Training School and discussed the training and certification of NDT operators. The discussion covered the various certification schemes, training requirements, training syllabus and the NDT process in general. A tour of the facilities was undertaken. A final wash up discussion was conducted.

5.1.2 Summary of Issues
- The general view was that the current training regime is able to produce competent ultrasonic operators.
- There is a need for the employing company to take charge of the operator. Training and certification needs to be integrated into the QA scheme.
• The employer (defined as the organisation for which the certificate holder works for on a regular basis) gives the operator authority to perform specific inspections.
• Employer based certification often has examinations on the content of a particular procedure.
• Decisions regarding indications should be covered by the procedure and should not be left to the operator. This would not de-skill the task of the operator who still has to apply the procedure and interpret the data.
• Although training covers the decisions that the operators are required to make in the application of a procedure, it doesn’t explicitly address decision making as a specific topic.
• The role of the Level 3 is not understood by all companies.
• Operators are being trained to pass an exam in that there is a syllabus and the questions are based on the syllabus.
• Training currently takes up whole weeks. Any changes to training and training requirements would require extra days, running into an extra week with the consequential difficulties for operators attending.
• The current system of renewals means that operators are under a lot of pressure to pass. If they fail they may not have a job to return to on the Monday after the exam.

5.1.3 Areas for Improvement
Two areas were identified as being important to the improvement of operator performance:

Better policing of the whole NDT process through QA and auditing. The aerospace industry has made improvements in this area through the NADCAP scheme.

More time for training with different levels of syllabus – even the operators sometimes wish they had more time for their training.

Note: a series of articles on NDT operator certification has been published in the BINDT Journal, INSIGHT [Ref. 12]

5.2 Operational NDT Unit Visit

5.2.1 Format
The project team met with two Senior Managers of an operational NDT unit. Again the visit started with a discussion. This covered the selection and training of operators, employment conditions, the management of NDT, work patterns, the role of the Level 3 and the characteristics of a “good” operator. Site working conditions were illustrated by a portfolio of pictures and a tour of the workshop allowed the team to meet with operators of varying experience and to observe them working.

5.2.2 Summary of Issues

Industry perspective
• There is an awareness of the variability of operators and steps are taken to try and manage differences in ability but the raw material of operators is not always of the desired standard.
• There is currently limited progression for NDT operators and NDT is no longer considered a career.
• As a result, the main motivation for operators is money. Although the pay is not good, money can be made from working long hours.
• Differences in attitude have been noticed between operators working from different industry sectors.

Operational NDT Unit considerations
• PCN gives a good general understanding of NDT application.
• Company training includes PCN plus in-house training in workshops plus on-site training prior to inspections.
• Operators are selected mainly on the basis of personal recommendations by people known to the company’s staff.
• Educational requirements are specified for own staff but do not rank highly. With contract staff the emphasis is put on NDT qualifications.
• The lack of resource has led to NDT apprentices being taken on.
• Operators have been given full time contracts to ensure supply and encourage teamwork.
• Operator performance is monitored through a registration scheme, audit reports and an end of contract assessment.
• The key to a good inspection is knowledge of the defects requiring detection.
• Hours are not limited and long hours can be required to provide job continuity but people are responsible for their own hours of working within a shift pattern.
• Operators are supervised and given the time to do a good inspection.
• Operators are assigned work in a way that avoids high reliability inspections being performed when they are likely to be below par.
• The supervision has been shown to work through the reduction in audit failures.
• The knowledge of Level 3 operators is important but the certification is only required for procedure acceptance. Level 3 is not required for supervisory roles.

5.2.3 Areas for Improvement
When asked what would improve NDT, the areas identified were:

- Reduction in the re-qualification burden to reduce costs and demands on time.
- Better policing of the NDT process to ensure correct application.

The former stimulated a discussion on performance based qualification. It was suggested that a mandatory log book system would provide improvements in both the above areas.

5.2.4 Ideal Operator
In the talk on the selection and training of operators the question was asked regarding the attributes of an “Ideal” Operator. These were identified as:

1. Integrity – the confidence to say “I don’t know”.
2. Experience
3. Education – proof of training
4. Qualification – certificates
5. Enthusiasm
6. Pro-active
7. The willingness to take time out to increase understanding
8. Interest
9. Team worker
10. Physical aspects to cope with conditions
11. Dexterity
12. Tenacity
13. Wisdom – the ability to apply knowledge

6 General Discussion

The recommendation arising from the literature review was that work be performed on the following factors:

- the organisation and organisational support for NDT (including the type and nature of the industry)
• the individual aspects of NDT such as the attitudes, the characteristics of the operators and the skills acquired
• the decision making process (including perception of risk).

Each of these factors has been addressed to a greater or lesser extent in each of the data collection activities described above – namely the literature review, the operator workshop and the visits to the training centre and the operational NDT unit. The outcomes of the activities relevant to the three factors are discussed below with a view to establishing the work for the remainder of the PANI 3 project.

6.1 The Organisation

The literature review concluded that the ‘organisation’ can often be overlooked during investigation into operator performance, but can have the greatest influence on individual and group behaviour. The ‘organisation’ refers to both the NDT management / NDT service company and the client for the NDT and covers activities such as:

• planning
• safety
• communication
• management
• culture

The importance of these factors was emphasised during the operator workshop and illustrated in the ideal processes suggested by the operators. The planning and preparation for a job transferred more and more on to the operator as the process moves from the ideal to that for a jobbing inspection. Safety was a priority for the operators, who again shoulder the majority of the responsibility when undertaking jobbing inspections (see comment on training below).

Communication has never been easier to implement but if we consider the information transfer aspect then there is a lot of room for improvement. A key improvement identified by the operators was the need to address the lack of client awareness of NDT requirements and best practice. As Behravesh, Karimi and Ford [Ref. 5] state: “If a plant (read client) meets its obligations in terms of provision of support, co-operation and pre-planning the chances of a successful outcome (of NDT) are greatly enhanced.”

The literature review highlighted the conflict faced by operators in deciding on whether to report a signal as a defect or not. Thapa et al [Ref. 13] refer to this as the operator’s response criterion and reflects the operator’s bias or tendency to call an item conforming or non-conforming. The setting of this criterion is influenced by the defect probability and the cost and values associated with the correct and incorrect responses. Thapa et al go on to state that any strategy to improve decision making performance should promote an optimal response strategy. Their paper investigates training strategies to improve decision making and concludes that feedforward training i.e. providing the operator with prior knowledge of defect characteristics and the probability of defects is effective in assisting operators in setting their response characteristics closer to the optimum. This is consistent with the suggestion of Behravesh, Karimi and Ford [Ref. 5] that training efforts should be altered to accommodate the conflicting directives that may be communicated to the operators. A key input to this is a clear statement of the client’s requirements from the inspection which everyone signs onto.

The visit to the operational NDT unit highlighted the management effort that was deemed necessary to support and supervise the NDT operators. This approach had been vindicated by an improvement in audit results and is in accordance with the various studies referred to in the literature review. The ideal processes identified by the operator all required better management especially in the preparation stage. The management support that is provided to operators is not always obvious to the client company and hence the client does not appreciate the true value of the service.

Time pressure was an area identified by the operators where improvements could be made through better management. It is acknowledged that, as with environmental factors, time pressures
cannot always be removed and some constraint can speed up the inspection without a consequential drop in performance. However, this needs to be tailored to the individual and, according to both operator comments and research, should also consider time on duty, time since last break from work and time since last reportable indication.

Again Behravesh, Karimi and Ford [Ref. 5] suggested that a way forward is the use of a more standardised code of managerial conduct.

One aspect which stands out from the operator workshop and the visits, is the lack of utilisation of the Level 3 operator. Whilst the Level 3 knowledge was required, the role appeared to be restricted to approving procedures and reviewing reports in the ideal NDT process.

**Training** is one aspect of operator management. As highlighted by the literature review, NDT training is focussed on the inspection task and does not address other key skills required for the operator role such as planning and decision making, reporting and stress management. The result of this being that operators are qualified, but are not practically prepared for the role at the knowledge based level.

Training has been shown to have a significant effect on correct decision making in inspection tasks. [Ref. 14]. Feedback on an operator's performance improves the ability to discriminate defects from other echoes whilst feedforward training (see Section 3.2 Glossary for definition) was seen to be more effective in assisting operators in setting their response strategy closer to the optimum (see paragraph above on communication) [Ref. 13]. Whilst the training schools use both feedback and feedforward training when preparing operators for the qualification examinations, the above highlights the importance of undertaking on the job training for specific inspections. The working practices described in the operational NDT unit visit include the operator being given knowledge of the defects requiring detection, pre-inspection training and a work instruction which details the job, gives the reporting requirements and says what will be done with the results so that the operator can see the importance of his work. From the training school visit it was evident that each operator benefits from training tailored to their individual needs and that “one size fits all” is not necessarily the best solution. The operators attending the workshop also highlighted on the job training and ongoing training as an area for improvement.

### 6.2 Individual Aspects

The literature study identified that there appears to be a mismatch between the type of candidate required for NDT and the requirements of the NDT task. The effect of this mismatch on an inspection has been described in the paragraph on communication above. Another study by Gramopadhye et al [Ref. 15] showed that those operators classified more risky in the workplace detected fewer defects, scored lower on the completion of workcards after the inspection and had lower accuracy performance.

At the PANI 2 results seminar, the attendees stated that they knew who their best operators were. It is likely that if they had been asked they would have come up with a similar list of characteristics to that given in Section 5.2.4. This list matches that identified by Behravesh, Karimi and Ford [Ref. 5] which identified conscientiousness, stress-tolerance, knowledge and self-efficacy as key personal factors and went on to summarise the most salient factors as pre-planning and professionalism. However, as identified by the literature review, the ‘individual’ aspects that affect task performance - personal attitude, skills, habits and personalities - can be strengths or weaknesses depending on the nature of the work including the physical characteristics, the workplace and working environment.

The literature review reported that Harris [Ref. 8] had identified general cognitive ability, abstract reasoning and spatial visualisation as being good indicators of operator performance. Thackray [Ref. 16] shows the correlation of mechanical aptitude with a lower number of missed defects and false alarms.
7 Further Investigative Work

7.1 The NDT Process

The ideal NDT process identified by the operators in the workshop will be developed further with particular reference to the areas discussed in Section 6 i.e.

- Planning and preparation
- Safety
- Communication
- Management
- Training

The process will then be discussed with managers of NDT service companies in the next part of the PANI 3 project, with a view to agreeing improvements in working practices.

7.2 Decision Making Process

Following the PANI 2 project, an initial review of previous work identified the decision making part of the manual ultrasonic inspection process as being a key area requiring further investigation. Hence this PANI 3 project was designed to gather experimental data on this aspect.

Although the more detailed literature review, described above, has described a number of papers on decision making, it concluded that it was worthwhile investigating further the information and decision making requirements of ultrasonic inspection and the operator’s perception of risk.

Based on the knowledge that the principal signal characteristics which provide the operator with information on the nature of the reflector are:

- Amplitude
- Rise-time
- Dynamics
- Peaks or facets
- Location
- Continuity
- Reference Comparison

and that the 4 factors which have been identified as being important for the correct sentencing of defects are:

- Develop and test explicit hypotheses as an integral part of the inspection process.
- Avoid reaching a conclusion early in the inspection process, before all available information has been obtained and considered.
- Apply knowledge during the inspection by putting it in the form of IF-THEN logic.
- Avoid the arbitrary or inadvertent elimination of information from consideration during the process of reaching an inspection conclusion (i.e. disregard of evidence).

It is proposed to investigate the decision making processes of a selection of operators using manufactured test pieces.

7.3 Operator Ability

In addition to investigating the decision making process, the opportunity will be taken to investigate the correlation between an operator’s performance on selected ability tests with the performance on the test pieces. The potential benefit of doing this is the identification of appropriate ability tests which could assist with the selection of new operators and with the identification of training needs for existing personnel.

7.3.1 Consideration of Tests

The proposed assessments were derived from a consideration of the following requirements:
1. The assessments clearly relate to the important individual differences variables identified within this report.
2. The assessments have been subjected to independent review and are at or exceed the ‘adequate’ threshold.
3. The assessments are at an appropriate level of difficulty for the test takers.
4. The total assessment period can be accommodated within the experimental phase of PANI-3.
5. The financial cost of assessment is reasonable.

Mechanical Ability

The literature review identified that Harris [Ref. 8] described general cognitive ability, abstract reasoning and spatial visualisation as being good indicators of operator performance. Thackray [Ref. 16] also indicated a strong association between operator detection accuracy and a Mechanical Aptitude Factor.

The Applied Technology Series (ATS) of tests published by SHL (UK Ltd) appear to meet these requirements. The ATS are described as assessing skills for working in the high-technology sector (e.g. mechanical and electronic engineering, process control). There are six tests within the series, and these fall into two groups. The first three tests are designed to measure more general aptitudes of ‘Following Instructions’, ‘Numerical Estimation’ and ‘Mechanical Comprehension’. These three tests are described as suitable for people with ‘basic educational attainments’. The other three tests are more specifically aimed at aptitudes related to new technology. These are: ‘Fault Finding’, ‘Spatial Checking’ and ‘Diagrammatic Thinking’. This second group of tests is described as suitable for people who ‘have obtained or are capable of obtaining at least a moderate level of educational attainment (e.g. good GCSEs, good CSEs or O-Levels)’.

The individual tests are described as follows:

Following Instructions (VTS1) - measures the ability to understand written instructions (in a technical context).

Numerical Estimation (NTS2) – measures the ability to estimate quickly the answers to numerical calculations.

Mechanical Comprehension (MTS3) – measures the understanding of basic mechanical principles.

Fault Finding (FTS4) – measures the ability to locate faults in a complex system.

Spatial Checking (STS5) – measures the ability to locate differences between complex designs rotated or reversed in two or three dimensions.

Diagrammatic Thinking (DTS6) – measures the ability to follow a symbol through a flow chart given a sequence of pre-defined instructions.

The British Psychology Society (BPS) review of the ATS states that there are significant correlations between most of these six tests. This is likely to reflect the tests relationships with a general ability factor. The ‘Numerical Estimation (NTS2)’ test would appear to be the most independent measurement. The BPS review reports that, for a combined group of students and apprentices, the correlations between FTS4, STS5 and DTS6 are quite high (correlation coefficient $r = 0.48$ to $r = 0.53$). This suggests that ‘Fault Finding’, ‘Spatial Checking’ and ‘Diagrammatic Thinking’ have a strong common spatial factor but are nevertheless distinct enough to be considered as separate aptitudes. The BPS review considers these three tests to use fairly novel item types, and thus we might consider these tests to be more strongly related to abstract reasoning than the first three within the series.

Personality
The work by Behravesh, Karimi & Ford [Ref. 5] identifies conscientiousness, stress-tolerance, knowledge and self-efficacy as key common factors associated with effective NDT performance. These factors overlap with those of an ‘ideal operator’ as derived from the operational NDT unit visit (see section 5.2.4 above). Gramopadhye et al [Ref. 15] also identified a relationship between defect detection and self-reported willingness to take risks when making decisions (as measured by the ‘responsible risk-taking inventory’). These factors appear to relate strongly to the discussion of the ‘Current Situation’ in Section 3.5.

An appropriate personality test is Gordon's Personal Profile Inventory (GPP-I), published by ASE. The GPP-I measures eight personality traits in a ‘forced choice’ format that aims to reduce the potential for ‘faking good’. A brief description of the eight aspects of personality measured by the GPP-I is given below.

Ascendancy (or self-assuredness) – the degree to which an individual adopts an active role in the group, makes independent decisions and is self-assured in relationships with others

Responsibility – the degree to which an individual sticks to the job assigned to them, is persevering and determined and can be relied upon

Emotional Stability – the degree to which an individual is free from worry, anxieties and nervous tension

Sociability – the degree to which individuals like to be with and work with people

Self-esteem – the sum of the above four scales provides the score for self-esteem (i.e. Ascendancy, Responsibility, Emotional Stability and Sociability)

Cautiousness – the degree to which an individual considers matters before making a decision, takes chances or runs risks

Original Thinking – the degree to which an individual tends to be intellectually curious or the extent to which they dislike working on difficult or complicated problems

Personal Relations – the degree to which an individual has trust in people and is tolerant, patient and understanding

Vigour – higher scores indicate vigour, energy and the ability to accomplish more than the average person

7.4 Proposed Experimental Work

7.4.1 Objectives
1. To investigate the decision making process of NDT operators
2. To find a correlation between the quality of the decisions and the performance in ability tests.

7.4.2 How to Meet the Objectives
In order to meet objective 1 it will be necessary to record the decision making process of the operators. This will be achieved by the following:

- Operators inspect test pieces containing in-service defects and geometric responses in an inspection scenario i.e. apply procedure, record indications, report defects.
- Operators will be observed and de-briefed on completion of each test piece inspection and all working will be collected.
- Test pieces will be designed to test different decision scenarios i.e.
  - Echo type – specular, mode conversion, corner
  - Echo position
- Echo dynamic
- Response on other probes
- Amplitude
- Comparison with other positions on the component

Finally, operators will be asked to perform a theoretical defect assessment. They will be shown a few diagrams of defects in a component and asked to describe how they would expect to detect them and show that they were present.

In order to meet objective 2 it is necessary to have some performance criteria on the test block exercise so that the results of the ability test can be correlated with performance. This will be established by the following measures:

- Correct sentencing of the indications i.e. detection and characterisation and location and sizing within specified limits.
- Comparison of operator’s approach compared to an ideal approach agreed prior to the inspection and incorporating best practice based on current knowledge e.g. results from experienced operator, the 9 information processing factors identified by Harris [Ref. 4].
- Performance on the hypothetical defects against agreed ideal answers.

7.4.3 Proposed Methodology
The original plan for the project was based around 45 operators attending for 1 day each in groups of threes i.e. fifteen days of testing. However, from a logistics point of view it will be preferable to have two operators attending at any one time.

It is proposed that the operators will inspect two test pieces of the same geometry which will contain defects as described above.

The theoretical defect assessment will cover two defects in a different geometry to the test pieces.

7.4.4 Timings
The timetable will be as shown in Table 1.

The ability tests will be undertaken in two periods of 1.15 hours and 1.45 hours. This total of 3 hours gives sufficient time to perform all six of the Applied Technology Series of tests, which are estimated to take 2 hours, and the Gordon’s Personal Profile Inventory, which will take about 20 minutes.
### Table 1 Timings for the Experimental Work

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>08.30</td>
<td>Briefing on Day</td>
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<tr>
<td>09.00</td>
<td>Ability Tests</td>
</tr>
<tr>
<td>10.30</td>
<td>Break</td>
</tr>
<tr>
<td>10.45</td>
<td>Ability Tests</td>
</tr>
<tr>
<td>12.15</td>
<td>Lunch</td>
</tr>
<tr>
<td>12.45</td>
<td>Calibration</td>
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<tr>
<td>13.15</td>
<td>Test Piece 1 (2 hours including de-brief)</td>
</tr>
<tr>
<td>15.15</td>
<td>Break</td>
</tr>
<tr>
<td>15.30</td>
<td>Test Piece 2 (1 hour 45 including de-brief)</td>
</tr>
<tr>
<td>17.15</td>
<td>Break</td>
</tr>
<tr>
<td>17.30</td>
<td>Theoretical Assessment</td>
</tr>
<tr>
<td>18.00</td>
<td>Finish</td>
</tr>
</tbody>
</table>

7.4.5 **Test Piece & Theoretical Assessment Design**

It is proposed that the test pieces and the theoretical assessment will be designed by an agreed team of three people. The ideal answers against which performance will be judged will be produced by this group.

More than 2 test pieces will be produced in order to assist in maintaining the confidentiality of the test piece information.

7.4.6 **Conduct of Ability Tests**

These tests will be supervised and assessed by suitably qualified and experienced personnel (SQEP) from Manchester Metropolitan University.

7.4.7 **Recording of Decision Making Process**

The protocol for the recording of the operators’ decision making processes will be agreed between the project team and the Human Factors Consultant and written up as a report. IVC staff and the Human Factors Consultant shall supervise the operators during the experimental work and will collect the relevant data.

### 8 Conclusions & Recommendation

1. A data gathering exercise, encompassing a literature search, a workshop to collect the views of operators and visits to an NDT training school and an operational NDT unit, has been successfully completed and has raised a number of issues for examination in the next phase of the project.

2. The information presented in the report supports the proposed experimental investigation into the decision making process and the proposed investigation into the correlation between the quality of the decisions and the performance in ability tests.

3. The following areas have been identified as areas where changes can be made to the inspection process in order to improve the reliability of manual ultrasonic inspection:
   - a. Planning and preparation
   - b. Safety
   - c. Communication
   - d. Management
   - e. Training
4. It is recommended that both the QA process assessment and the experimental work proposed in Section 7 be undertaken.

9 References


Interim Report Appendix 1
PANI 3 Operator Workshop
# PANI 3 Operator Workshop

Monday 10 October 2005  
Risley

## Programme

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.00</td>
<td>Coffee</td>
<td></td>
</tr>
<tr>
<td>10.30</td>
<td>Welcome &amp; HSE Viewpoint</td>
<td>Harry Bainbridge</td>
</tr>
<tr>
<td>10.45</td>
<td>Introduction to PANI &amp; Today’s Workshop</td>
<td>Bernard McGrath</td>
</tr>
<tr>
<td>11.00</td>
<td>Process Mapping Activity</td>
<td>Mike Duff</td>
</tr>
<tr>
<td>11.15</td>
<td>Breakout Session 1 – What process do you currently apply when doing manual UT?</td>
<td>Groups</td>
</tr>
<tr>
<td>11.45</td>
<td>Report Back 1</td>
<td>Mike Duff</td>
</tr>
<tr>
<td>12.30</td>
<td>Lunch</td>
<td>All</td>
</tr>
<tr>
<td>1.15</td>
<td>Breakout Session 2 – What interactions do you have with your management and the client?</td>
<td>Groups</td>
</tr>
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<td>Report Back 2</td>
<td>Mike Duff</td>
</tr>
<tr>
<td>2.15</td>
<td>What process would you like to apply to assist you in your job?</td>
<td>Groups</td>
</tr>
<tr>
<td>2.45</td>
<td>Report Back 3</td>
<td>Mike Duff</td>
</tr>
</tbody>
</table>
| 3.15  | Open Discussion  
Ideal interactions  
Other issues | Bernard McGrath |
| 4.00  | Close                                                                    |                   |
Appendix 3
Operator Details Form
As part of the exercise which you are involved in, we need to have a record of each operator’s qualifications, experience and training. This questionnaire is designed to record the necessary details.

It is emphasised that this information will be treated in confidence.

### Operator Details

| Name (first name and surname) |  |
| Age | years |
| Company name or self-employed |  |
| Number of years experience in NDT | years |
| Number of years experience in ultrasonic NDT | years |

On average how often do you inspect using ultrasonic NDT? (please ✓)

<table>
<thead>
<tr>
<th>Every day</th>
<th>More than once a week</th>
<th>More than once a month</th>
<th>More than once a year</th>
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</table>

### Operator Training

Please list below the training courses you have attended over the last 3 years

<table>
<thead>
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<th>Course title / description</th>
<th>Training organisation</th>
<th>Duration and date (month / year) e.g. 2 days, July 2000</th>
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### Operator Details Form

<table>
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<th>Course title / description</th>
<th>Training organisation</th>
<th>Duration and date (month / year)</th>
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<tbody>
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<td>e.g. 2 days, July 2000</td>
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</tbody>
</table>

### Operator Qualifications

Please record your qualifications below (or provide copies of certificates)
Please include any company, job-specific approvals here, as well as general ones such as PCN or ASNT.

<table>
<thead>
<tr>
<th>Qualification (including method, level, sector &amp; scope where appropriate)</th>
<th>Where obtained</th>
<th>When obtained (month &amp; year)</th>
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</table>
## Operator Details Form

<table>
<thead>
<tr>
<th>Qualification (including method, level, sector &amp; scope where appropriate)</th>
<th>Where obtained</th>
<th>When obtained (month &amp; year)</th>
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**Signed** | **Date**
Appendix 4
PANI 3 Test Pieces
PANI 3 – Manufacturing Specification of Test Pieces
Executive Summary

The Health & Safety Executive began the Programme for the Assessment of NDT in Industry (PANI) with a view to establishing and improving the effectiveness of NDT as applied in general industry outside of the nuclear industry. The objective of the current and third project, PANI 3, is to identifying solutions which will allow industry to optimise performance and minimise the magnitude of the variation in operator performance illustrated in PANI 2.

This document details the specification for the manufacture of the test pieces containing representative in-service defects which will be used for the experimental work in the PANI 3 project.
# Contents

1. **Introduction**  
   
2. **Design Philosophy**  
   
3. **Material**  
   
4. **Geometry**  
   
5. **Other Features**  
   - 5.1 Base Plate  
   - 5.2 Test Piece Markings  
   
6. **Welding Procedure**  
   
7. **Defect Specifications**  
   - 7.1 Test Piece P3TP01  
   - 7.2 Test Piece P3TP02  
   - 7.3 Test Piece P3TP03  
   
8. **Manufacturing Sequence**  
   
9. **Documentation & Deliverables**  

Appendix 4  
Manufacturing Specification of Test Pieces  
Page 3
1 Introduction

The Health & Safety Executive began the Programme for the Assessment of NDT in Industry (PANI) with a view to establishing and improving the effectiveness of NDT as applied in general industry outside of the nuclear industry. The objective of the current and third project, PANI 3, is to identifying solutions which will allow industry to optimise performance and minimise the magnitude of the variation in operator performance illustrated in PANI 2.

Following a data gathering and assessment exercise, experimental work has been proposed to investigate the decision making process of NDT operators and to find whether there is a correlation between the quality of the decisions and the performance in ability tests. This experimental work requires that operators inspect test pieces containing in-service defect and geometric responses in an inspection scenario i.e. apply procedure, record indications, report defects.

This document details the specification for the manufacture of the test pieces containing representative in-service defects. The experimental procedure and the results achieved will be presented in separate reports.

2 Design Philosophy

The test pieces have been designed to present the operator with different decision scenarios i.e.
- Echo type – specular, mode conversion, corner
- Echo position
- Echo dynamic
- Response on other probes
- Amplitude

An unfused land and the weld caps are intended to produce geometric echoes which will add to the ultrasonic signal assessment requirements.

The requirement to compare operator performance against performance in ability tests means that as many operators as possible are to inspect the same test pieces. It is also desirable to have test pieces of same geometry so that the number of variables in the experiment are minimised.

The T-Joint weld geometry as used in PANI 2 has been selected on the basis that it gives a variety of defect type and geometric options to test the decision making of the operators.

However, there is a need to maintain the security of the defect information. This will be achieved by manufacturing three test pieces, using a circular geometry and varying the defect populations.

3 Material

All three test pieces will be constructed out of ferritic steel.

The overall finish of the test specimens is intended to be as realistic as encountered on site locations.

4 Geometry

The weld geometry will be similar to that used in the PANI 2 T-Joint test piece. However, instead of a linear weld, the weld will be circular. This is achieved by welding a 20 mm thick disc to the inside
of an 8 inch diameter, schedule 80 pipe. 8 inch diameter pipe has an external diameter of 219 mm and schedule 80 has a wall thickness of 0.5 inch or 12.7 mm.

The geometry of the test piece is given in Figure 1 and Figure 2.

The pipe has an overall length of 180 mm and the plate is welded so that the centre line of the plate is a distance of 50 mm from the end of the pipe. The weld on the face of the plate which is 40 mm from the end of the pipe is the upper weld. The weld on the other side of the plate is the lower weld.

The upper weld is a penetrating weld with a 45° fusion face. The lower weld is a fillet weld which leaves a 10 mm unfused land in the centre of the joint.
Figure 2 Cross Sectional View of the Test Piece Geometry

Figure 3 Details of Base Plate
5 Other Features

5.1 Base Plate

In order to prevent the operator from observing any defects in the lower weld, a base plate will be used. The base plate will be a thin circular plate of 320 mm diameter. It will be fixed to the lower end of the pipe with six screws equally spaced at 60° intervals around the circumference as shown in Figure 3.

5.2 Test Piece Markings

No marks will be put onto the external or upper internal surfaces of the pipes.

The test piece identification number and the 0° datum mark will be inscribed on the internal surface of the pipe at the lower end. The operators will not be able to see these markings once the base plate is fixed in position.

6 Welding Procedure

The welding procedure shall be selected by the manufacturer. However, the weld shall be laid down in such a manner that the weld caps shall be irregular and contain excess material.

7 Defect Specifications

The defects to be inserted in the three test pieces are specified below:

7.1 Test Piece P3TP01

This test piece will contain 2 defects.

Defect 1 is a crack extending 4 mm from the unfused land and running along the pipe fusion face as shown in Figure 4.

Defect 2 is a crack at the toe of the upper weld on the disc side of the weld. It has a height of 2.5 mm and is angled into the disc at 10° to the fusion face as shown in Figure 4.

The circumferential positions and lengths of the defects are shown in Figure 5. The positioning of the defect in the circumferential direction is not critical as long as the actual position is recorded during manufacturing.

Defect 1 is positioned 25 mm around from the top dead centre (TDC) in a clockwise direction. The length of Defect 1 is 30 mm.

Defect 2 is positioned 45 mm further around from 270° position from the top dead centre (TDC) in a clockwise direction. The length of Defect 2 is 25 mm.
Figure 4 Defects in Test Piece P3TP01

Figure 5 Circumferential Positions of Defects in P3TP01
7.2 Test Piece P3TP02

This test piece will contain 3 defects.

Defect 1 is a crack extending 4 mm from the unfused land and running along the pipe fusion face as shown in Figure 6.

Defect 2 is a crack at the toe of the lower weld on the disc side of the weld. It has a height of 2.5 mm and is angled at 30° from the perpendicular to the disc surface as shown in Figure 6.

Defect 3 is an erosion defect at the toe of the lower weld on the pipe internal surface. It penetrates quickly from the toe of the weld to a depth of 3 mm and then gradually reduces in depth over a width of 20 mm along the pipe axis as shown in Figure 7.

The circumferential positions and lengths of the defects are shown in Figure 8. The positioning of the defect in the circumferential direction is not critical as long as the actual position is recorded during manufacturing.

Defect 1 is positioned so as to end 30 mm before the 180° position around from top dead centre (TDC) in a clockwise direction. The length of Defect 1 is 30 mm.

Defect 2 is positioned so as to end 45 mm before the 270° position around from top dead centre (TDC) in a clockwise direction. The length of Defect 2 is 40 mm.

Defect 3 is centred on the 90° position around from top dead centre (TDC) in a clockwise direction. The length of Defect 3 is 30 mm.

Figure 6 Defects 1 and 2 in P3TP02
Figure 7 Defect 3 in P3TP02

Figure 8 Circumferential Positions of Defects in P3TP02
7.3 Test Piece P3TP03

This test piece will contain 4 defects.

Defect 1 is a LOSWF defect on the disc fusion face of the upper weld. It is situated at a depth of 5 mm down the fusion face and with a height of 3 mm along the fusion face as shown in Figure 9.

**Note:** although a LOSWF defect is not an in-service defect it is a planar defect which may be encountered during an in-service inspection and hence its inclusion in the test pieces.

Defect 2 is a crack at the toe of the lower weld on the disc side of the weld. It has a height of 4 mm and is perpendicular to the disc surface as shown in Figure 9.

Defect 3 is a crack at the toe of the lower weld on the pipe side of the weld. It has a height of 2.5 mm and is perpendicular to the pipe surface as shown in Figure 10.

Defect 4 is an erosion defect at the toe of the lower weld on the pipe internal surface. It penetrates to a depth of 3 mm and has a width of 5 mm along the pipe axis as shown in Figure 10.

The circumferential positions and lengths of the defects are shown in Figure 11. The positioning of the defect in the circumferential direction is not critical as long as the actual position is recorded during manufacturing.

Defect 1 is positioned 10 mm further around from 270° position from the top dead centre (TDC) in a clockwise direction. The length of Defect 1 is 30 mm.

Defect 2 is positioned so as to end 40 mm before the 270° position around from top dead centre (TDC) in a clockwise direction. The length of Defect 2 is 40 mm.

Defect 3 is positioned so as to end at the 180° position around from top dead centre (TDC) in a clockwise direction. The length of Defect 3 is 35 mm.

Defect 4 is positioned so as to start 40 mm before top dead centre (TDC) and end 60 mm around from TDC in a clockwise direction so that the overall length of Defect 4 is 100 mm.
Figure 9 Defects 1 and 2 in P3TP03

Figure 10 Defects 3 and 4 in P3TP03
8 Manufacturing Sequence

The manufacture of Test piece P3TP03, which contains 4 defects, will be completed and delivered prior to the defects being implanted into the other two test pieces.

The geometric and defect ultrasonic signals from the test piece will be assessed by Serco Assurance in the light of the objectives of the experimental work. This assessment may require that there be changes to the dimensions of the defects to be implanted into the other test pieces. The manufacture of the defects for the two test pieces, P3TP01 and P3TP02 shall not commence until Serco have give written permission to do so.

9 Documentation & Deliverables

The following items shall be delivered with the test pieces:

- Full QA package associated with manufacture i.e. material certification, welding details, defect manufacturing details etc.
- An as-made drawing of each test piece showing defect location and size.
Appendix 5
Ultrasonic Procedure Used
For PANI 3 Inspections
Procedure for the Ultrasonic Inspection of PANI 3 Test Pieces

Based on BS EN 1714
Procedure No. PANI 3 01

Author: Jim Wheeler

Level III Approval: Nick Turner

Approved: Bernard McGrath

Authorised Copy No.

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<tr>
<th>Issue</th>
<th>Amendment</th>
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<td>7/06</td>
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<td>2</td>
<td>Section 12 Scan Diagram Updated</td>
<td>8/06</td>
</tr>
<tr>
<td>3</td>
<td>Defect / Flaw Terminology replaced.</td>
<td>8/06</td>
</tr>
</tbody>
</table>
1 SCOPE

This procedure details the requirements for the manual ultrasonic examination of the PANI 3 welded ferritic samples. It meets the requirements of EN 1714.

The procedure gives all the requirements for the inspections.

The aim of the inspection is to detect, locate and evaluate recordable indications.

2 PERSONNEL

The examination shall be performed by qualified personnel, certificated to PCN Level 2 Ultrasonic Weld Testing or its equivalent in a category appropriate to the geometry of the item.

3 EQUIPMENT

The following equipment shall be used for the examination:

3.1 Flaw Detector

A flaw detector with an A-scan presentation. The flaw detector performance shall be checked against the appropriate requirements of BS EN 12668-3:2000.

3.2 Probes

Note the probes will be provided by the Inspection Validation Centre (IVC) as detailed below:

Parent material examination:

- $0^\circ$ twin crystal compression, 10mm dia., 5 MHz

Weld examination:

- a) $0^\circ$ twin crystal compression, 10mm dia., 5 MHz
- b) $45^\circ$, $60^\circ$ and $70^\circ$ single crystal shear wave, 10mm dia., 4MHz

The probe performance shall be checked against the appropriate requirements of BS EN 12668-3:2000

3.3 Calibration Blocks

The Cal 1 (A2) and Cal 2 (A4) blocks for time base calibration (BS EN 12223 and 27963:2000).

3.4 Reference Block

A reference block containing 3mm dia. SDH’s for sensitivity calibration – DAC (BS EN 583-2 Annex B).

N.B. An alternative block containing 1.5mm dia. SDH’s may be used instead of the 3mm hole block; in this case any gain settings should be reduced by 3dB in order to achieve the required sensitivity.
3.5 Couplant

Ultragel couplant shall be used for both calibration and inspection.

4 SURFACE CONDITION

The scanning surface shall be free from foreign matter and the test surface shall not have a gap between the probe and test surfaces greater than 0.5mm.

5 EQUIPMENT CHECKS PRIOR TO EXAMINATION

5.1 Time Base Linearity

The linearity of the time base shall be carried out weekly in accordance with BSEN12668 PT3.

5.2 Amplifier Gain

The linearity of the equipment gain shall be carried out weekly in accordance with BSEN 12668 PT 3.

5.3 Sensitivity & Signal to Noise

The sensitivity and signal to noise ratio shall be carried out prior to the PANI 3 inspection in accordance with BSEN 12668 PT 3.

5.4 Probes

The following probe checks shall be carried out prior to the PANI 3 inspection in accordance with BSEN12668 PT3:

(a) Probe index
(b) Beam Angle

Note: a weekly Beam Profile check will be performed by the IVC and the information provided.

6 CHECKS DURING EXAMINATION

Following the initial calibration of the equipment the calibration shall be checked during detection and evaluation.

a) At least every 4 hours.

b) At any time misadjustment is suspected.

c) After change in operator or equipment

d) At the end of each work shift

If a decrease of more than 2dB’s in sensitivity is observed the calibration shall be corrected and all areas inspected since the previous review shall be re-examined.

7 SCANNING REQUIREMENTS

0° twin compression wave probes shall be scanned with their acoustic barrier normal to the scanning direction.

To ensure full coverage each scan of the probe shall be overlapped by at least 50% of the crystal width or diameter.
The maximum scanning speed shall not exceed 100mm/second. Fixed root scans 25mm/second.

All recordable indications and conditions shall be recorded relative to the datum system appropriate to the component. This shall be referenced in the final report.

If any part of this procedure cannot be conformed to satisfactorily it should be reported immediately to the IVC.

A copy of BS EN 1714 shall be available during the inspection.

8 EXAMINATION

8.1 Parent Material

The parent material of the component adjacent to the weld shall be examined with the 0° twin crystal probe to determine:

(i) Material thicknesses
(ii) To locate any imperfections which could affect the subsequent angle beam examination of the weld

The parent material shall be examined as follows:

Calibrate the timebase of the flaw detector so that a minimum of two backwall echoes from the parent material are displayed on screen (A4 block).

Examination sensitivity = 2nd BWE to 100% FSH

Examine the parent material for a distance back from the weld equal to the maximum scanning distance used on the subsequent angle beam examination of the weld.

8.2 Weld

The complete weld including at least 10mm of the HAZ ie. 10mm into the parent plate from the weld fusion face, shall be examined, to locate and size recordable indications that may be present, from:

(i) Component manufacture i.e. LOSWF
(ii) In-service degradation i.e. erosion or fatigue – for these flaw types, particular interest should be paid to the surface regions of the weld adjacent to the root and the weld toes and to regions adjacent to unfused lands.

The weld shall be examined as follows:

Calibrate the timebase of the flaw detector to represent a suitable examination range for each scan i.e. 0 to 50mm, 0 to 100mm, 0 to 200mm (A4 block).

Examination sensitivity

DAC curves shall be constructed in accordance with BS EN 583-2. For components containing a thin wall section, the DAC shall be constructed over the examination range for the thicker wall section.

During scanning a slight oscillating rotational movement, up to 10° either side of the normal to the weld axis, shall be applied to the probes to aid the detection of skewed flaws.

Scanning shall be carried out at the gain used to construct the DAC curve plus 10dB.
9 EVALUATION

9.1 Parent Material Examination

The following shall be reported:

Indications ≥ 20% FSH at the examination sensitivity

A reduction in BWE to below 50% FSH

9.2 Weld Examination

The following shall be reported:

Indications ≥ 33% DAC

All indications shall be evaluated to assess:

a. Length
b. Ligament
c. TWE (Through Wall Extent)
d. Location
e. Character
f. Maximum Amplitude

Length shall be assessed using the −6dB Drop Method.
TWE shall be assessed using the Maximum Amplitude Technique or the −20dB Drop Method.

9.3 Order of evaluation

An initial evaluation to determine whether an indication is reportable shall be carried out when the indication is observed during 'search' scans. If the indication is reportable then the location along the weld shall be marked on the specimen and the approximate distance from the datum recorded on the 'Inspection results' form (Appendix 1). No further evaluation shall be performed at this time. Scanning shall then continue until all of the scans specified have been completed.

When all of the scans have been completed, the indications detected in the 'search' scans shall be evaluated in detail using the relevant probes

10 REPORTING

A report shall be prepared for each weld using the proformas given in Appendix 1. The report shall contain, as a minimum, the following information:

1) The operator's PANI 3 number.
2) Identification of the sample.
3) Procedure reference and issue number.
4) Date of test.
5) A list of equipment including flaw detector and probes used.
6) Couplant used.
7) Details of DAC and inspection sensitivities (flaw detector gain settings).
8) Details of inspection coverage, including areas of limited coverage due to surface profile, parent material quality, geometry or access problems.

9) Details of all reportable indications ≥ 33% DAC with measurable dimensions. The following should be recorded:
   - characterisation as planar or non-planar in accordance with BS EN 1713,
   - centre location given with respect to the datum point marked on the component,
   - the nearest surface and the ligament to this surface,
   - length,
   - through wall-extent,
   - the echo dynamic pattern as given in BS EN 583-5:2001 Annex B
   - amplitude of each indication expressed in dBS relative to the DAC.

10) Where the reportable indication has been sized using probe movement techniques the through wall dimension of the indication shall be shown on a full size cross-sectional drawing. The table of stand off and range measurements together with the stand off datum shall be completed.
11 REFERENCES

BS EN 12223:2000 Non-destructive testing. Ultrasonic examination. Specification for calibration block No.1

BS EN 27963:2000 Non-destructive testing. Ultrasonic examination. Specification for calibration block No.2


BS EN 583-2:2001 Non-destructive testing. Ultrasonic Examination. Sensitivity and Range Setting


BS EN 12668-3:2000 Non-destructive testing. Characterisation and verification of ultrasonic examination equipment. Combined equipment
12 SCAN DIAGRAM

Note: 0 degree scans to cover parent material interrogated by shear wave probes
## Appendix 1 - Report Sheet
### Inspection Details  Sheet 1 of 2

<table>
<thead>
<tr>
<th>Operator Number</th>
<th>Sample ID</th>
<th>Description</th>
<th>Procedure No.</th>
<th>Issue</th>
<th>Date of Test</th>
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### Equipment

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<th>Couplant</th>
<th>DAC block ID No.</th>
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### DAC and Inspection Sensitivities

#### a) Sensitivities set using Backwall Echo

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<th>Probe:</th>
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<th>Range (beam path) to Backwall [mm]</th>
<th>Amplitude of Backwall [%FSH]</th>
<th>Flaw detector Gain Setting for this amplitude [dB]</th>
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**Inspection Sensitivity:**
(e.g. 2nd BWE to 100%FSH)

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<th>Probe:</th>
<th>Backwall used: (e.g. 1st, 2nd)</th>
<th>Range (beam path) to Backwall [mm]</th>
<th>Amplitude of Backwall [%FSH]</th>
<th>Flaw detector Gain Setting for this amplitude [dB]</th>
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**Inspection Sensitivity:**
(e.g. 2nd BWE to 100%FSH)
b) Sensitivities set using DAC

<table>
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<td>(e.g. DAC + 10dB)</td>
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<table>
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<td>Inspection Sensitivity:</td>
<td>(e.g. DAC + 10dB)</td>
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<tr>
<td>Inspection Sensitivity:</td>
<td>(e.g. DAC + 10dB)</td>
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Give details of inspection coverage, including areas of limited coverage due to surface profile, parent material quality, geometry or access problems.
## Inspection Results Sheet

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### Indication No

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<th>Location of centre of Defect wrt datum</th>
<th>Length of Defect</th>
<th>Through Wall Extent</th>
<th>Ligation (mm)</th>
<th>Echoprint</th>
<th>Amplitude rel. to Recording Threshold (33% DAC)</th>
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<td>Final value</td>
<td>L (mm)</td>
<td>Sizing Technique</td>
<td>TWE (mm)</td>
<td>Sizing Technique</td>
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### Cross-sectional sketch of TWE of Defect

Table of the stand off and range measurements together with the stand off datum.

<table>
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Reported Lab
Appendix 6
Analysis of Test Data
Analysis of Test Data

A6.1 Analysis Procedure

The first stage in the analysis was to compare scores on the ability and personality measures obtained from the ultrasonic operators with norm data derived from a sample of UK adult males from a wide range of organisations and job types. This analysis was performed as a series of one sample t–tests¹ in which the mean score for the ultrasonic operator sample was compared with the mean score for the norm group.

The second stage in the analysis was to run a series of correlations² and a principal components analysis³ on the dependent measures derived from the manual ultrasonic inspection tasks:

- Flaw omission frequency
- Average defect position error
- Average defect size error
- False positives (False calls)

This analysis was undertaken in order to determine the extent to which individual indices of ultrasonic test performance were inter-dependent and to determine if the separate measures could be combined to produce a single index of performance. The production of a single index of ultrasonic test performance has the advantage of increasing the reliability of the performance measure. It also reduces the number of statistical tests to be performed with a resultant decrease in the likelihood of achieving a significant result due to chance factors.

If a single measure of ultrasonic test performance can be derived, then this could be correlated with operators’ scores on the ability tests, personality inventory and years of experience in undertaking NDT and manual ultrasonic inspections. Those variables demonstrating significant correlation with the single measure of ultrasonic test performance could then be entered into a multiple regression⁴ in order to determine their combined value as predictors of inspection performance.

A6.2 Comparison with General Population

Table A6.1 below shows the mean scores on the ability tests for the ultrasonic operators and how these compare with norm data gathered from samples of male applicants to a variety of jobs in various sectors of industry including engineering, transport and manufacturing.

¹ A one sample t-test assesses whether there is a statistically significant difference between the average scores produced by two groups
² A measure of the degree of the relationship between two variables, ranging from +1 (a perfect positive correlation) through zero (no correlation) to -1 (a perfect negative correlation)
³ Principal components analysis reduces data sets containing a large number of variables into a smaller number on the basis of their correlation
⁴ A statistical technique to determine the extent to which the scores on one variable (here, NDT performance) can be predicted from scores on other variables (here, ability test scores and personality scale scores)
Table A6.1: Comparison of ultrasonic operator Ability test scores with norms

<table>
<thead>
<tr>
<th>Test</th>
<th>Norm</th>
<th>Op Data</th>
<th>$t^5$</th>
<th>$p^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following Instructions</td>
<td>21.18</td>
<td>20.68</td>
<td>-0.58</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Numerical Estimation</td>
<td>18.17</td>
<td>23.90</td>
<td>5.75</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Mechanical Comp</td>
<td>14.35</td>
<td>17.40</td>
<td>4.01</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Fault Finding</td>
<td>16.74</td>
<td>14.13</td>
<td>-2.84</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Spatial Checking</td>
<td>22.08</td>
<td>16.58</td>
<td>-4.76</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Diagram Thinking</td>
<td>18.75</td>
<td>16.10</td>
<td>-2.46</td>
<td>P&lt;0.05</td>
</tr>
</tbody>
</table>

Ultrasonic operators perform better than the average worker on tests of Numerical Estimation and Mechanical Comprehension. They perform less well than the average worker on tests of Spatial Checking, Fault Finding and Diagrammatic Thinking.

The tables below provide details of each individual independent t-test and descriptive statistics for each ability test.

$^5$ $t$ is the calculated test statistic for the one-sample $t$ test. The larger the value of $t$ (either positive or negative), the more likely it is that the difference between the mean scores of two groups is not due to chance.

$^6$ $p$ is the probability of the calculated value for a test statistic arising as a result of chance (random) factors. If the value of $p$ is lower than 5%, i.e. $p<0.05$, then by convention the result of the statistical analysis is considered to be significant.
<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Ml</th>
<th>M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>----</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>S</td>
<td>8</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>h</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>6</td>
<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>h</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>9</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>
Table A6.2 below shows the mean scores on the personality inventory for the ultrasonic operators and how these compare with norm data gathered from a sample of male UK workers.

**Table A6.2: Comparison of ultrasonic operator personality inventory scores**

<table>
<thead>
<tr>
<th>Scale</th>
<th>Norm</th>
<th>Op Data</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascendancy</td>
<td>23</td>
<td>20.90</td>
<td>-2.91</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Responsibility</td>
<td>26.9</td>
<td>28.9</td>
<td>3.20</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Emotional</td>
<td>27.1</td>
<td>27.70</td>
<td>0.80</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Stability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sociability</td>
<td>22.2</td>
<td>20.15</td>
<td>-2.43</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Cautiousness</td>
<td>23</td>
<td>27.05</td>
<td>4.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Original</td>
<td>26.6</td>
<td>25.05</td>
<td>-2.02</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Thinking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal</td>
<td>23.9</td>
<td>22.59</td>
<td>-1.27</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Relationships</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vigour</td>
<td>26.5</td>
<td>25.44</td>
<td>-1.51</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>

Ultrasonic operators score higher than the average male UK worker on Responsibility and Cautiousness. They score lower on Ascendancy and Sociability.

The importance of these differences between the ultrasonic operator sample and the norm groups will be dependent upon the extent to which these variables are correlated with ultrasonic performance.

The tables below provide details of each individual independent t-test and descriptive statistics for each personality scale.
Analysis of Test Data

One-Sample Test

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotion Stability GPP-I</td>
<td>.801</td>
<td>.428</td>
<td>.600</td>
<td>-.92</td>
<td>2.12</td>
</tr>
</tbody>
</table>

Test Value = 27.1
Individual variables, revealed a single index of performance which correlated highly with each of the principal components analysis, based on the correlations between the ultrasonic performance dependent measures.

A6.3 Correlation with Ultrasonic Performance

A principal components analysis, based on the correlations between the ultrasonic performance variables, revealed a single index of performance which correlated highly with each of the individual ultrasonic performance dependent measures.

The results of the principal components analysis are presented below.
Table A6.3: Correlation between single index of performance and individual ultrasonic dependent measures

<table>
<thead>
<tr>
<th></th>
<th>Correlation with Single Index of Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flaw Omission Frequency</td>
<td>.629</td>
</tr>
<tr>
<td>False Positives</td>
<td>.578</td>
</tr>
<tr>
<td>Average Position Error</td>
<td>.818</td>
</tr>
<tr>
<td>Average size error</td>
<td>.627</td>
</tr>
</tbody>
</table>

These correlations between the individual ultrasonic dependent measures and the single index of performance were used to calculate an overall ultrasonic performance score for each operator. The overall performance is based on the combination of the individual error measures listed in Table A6.3 and is therefore a single measure of overall ultrasonic error.

The overall ultrasonic error scores were then correlated with operators' scores on each of the ability tests. A significant negative correlation was found between the overall ultrasonic error performance scores and the test scores for Mechanical Comprehension ($r^7 = -0.352$, $N^8 = 37$, $p$

---

7 $r$ is the calculated test statistic (correlation coefficient) for the Pearson Product Moment Correlation.

8 $N$ is the number of pairs of scores used in calculation of the correlation coefficient.
Operators with higher Mechanical Comprehension have lower overall ultrasonic error performance scores. One tailed tests were utilised here based on the conclusion in the literature review that ultrasonic performance was associated with mechanical aptitude, spatial visualisation/abstract reasoning and general cognitive ability. Cohen (1992) argues that for r, coefficients of 0.1 should be considered small effect sizes, those of 0.3 medium effect sizes and those of 0.5 large effect sizes. The above correlation between overall ultrasonic error scores and the test scores for Mechanical Comprehension should therefore be considered a medium effect size.

Overall ultrasonic error scores were also correlated with each of the personality variables. Significant positive correlations were found between overall ultrasonic error scores and Sociability ($r = 0.354, N = 40, p = 0.032, \text{two-tailed}$); Cautiousness ($r = 0.387, N = 37, p = 0.02, \text{two-tailed}$) and Original Thinking ($r = 0.353, N = 37, p = 0.035, \text{two-tailed}$). Operators lower in Sociability, Cautiousness and Original Thinking have lower overall ultrasonic error scores. Two tailed tests were used in the analysis of these personality variables because the literature does not provide a sufficiently clear basis from which directional hypotheses could be derived. The above significant correlations between overall ultrasonic error scores and the personality variables should be considered as medium effect sizes.

A final set of correlations was computed between overall ultrasonic error scores and years of experience in both general NDT and manual ultrasonic inspection. These revealed a significant negative correlation between years of manual ultrasonic inspection experience and overall ultrasonic error score ($r = -0.315, N = 37, p = 0.028, \text{one-tailed}$). However, there was no significant correlation between years of general NDT experience and overall ultrasonic error score.

From the analyses described above, five variables were found to correlate significantly with the overall ultrasonic error scores:

- Mechanical Comprehension
- Sociability
- Cautiousness
- Original Thinking
- Years of manual ultrasonic test experience

These five variables were entered into a multiple regression to determine the extent to which overall NDT error score could be predicted from the variables in combination. The correlation between the five variables and the overall ultrasonic error score was $R^{2} = 0.72$ which demonstrates that the variables account for 52% of the variance in the overall ultrasonic error scores. Of the variables entered into the regression equation, three were found to account for significant unique variance in overall ultrasonic error score: Mechanical Comprehension ($t = -3.12, p=0.004$), Cautiousness ($t = 2.54, p=0.017$) and Original Thinking ($t = 2.59, p=0.015$). Sociability and Years of manual Ultrasonic NDT experience did not add to the prediction of overall ultrasonic error scores, once the contribution of Mechanical Comprehension, Original Thinking and Cautiousness had been taken into account.

The tables below provide details of the multiple regression for the five variables.

---

9 A one tailed test is one in which the direction of the relationship (positive or negative) between two variables is predicted at the outset of the study.
10 An effect size is an index of the importance of the statistical relationship between variables.
11 A two tailed test is one in which the direction of the relationship between two variables is not predicted at the outset of the study.
12 $R$ is the multiple correlation coefficient representing a measure of the overall association between a dependent variable (here, overall NDT error score) and the combination of predictor variables used in the regression equation.
Removal of non-significant predictors from the regression equation (Sociability, Years of experience), resulted in a regression model that accounted for 51% of the variance in overall ultrasonic error score. In terms of importance, the effect size is above Cohen's characterisation of a large effect in which 25% of the variance is explained.

The tables below provide details of the multiple regression after the removal of the variables Sociability and years of experience.
A6.4 Conclusions

From the analysis conducted above it can be concluded that within this sample overall ultrasonic error performance is related to scores on the test of Mechanical Comprehension and the personality variables Cautiousness and Original Thinking. Interestingly these variables are more powerful predictors of manual ultrasonic inspection performance than the number of years of experience an operator has in performing this task.

The results reveal that good manual ultrasonic inspection performance is associated with high scores on the test of Mechanical Comprehension and low scores on the personality variables Cautiousness and Original Thinking. The result in relation to Mechanical Comprehension is consistent with evidence presented in the literature review (Appendix 2) and confirms the importance of this ability for ultrasonic inspection.

The result in relation to personality scores may appear more unexpected. In the case of cautiousness, however, it should be remembered that the mean score on this scale for the ultrasonic operators was significantly higher than the norm for UK employed males. Thus those operators who score high in relation to other operators within the ultrasonic operator group could be described as over-cautious whilst those who score low in relation to other ultrasonic operators may in fact display a level of cautiousness which is consistent with the average UK male worker. Thus the results could be interpreted as showing that those operators who display an average level of cautiousness, in relation to the general population, are better suited to the ultrasonic inspection task.

In relation to Original Thinking, high scores on this variable suggest a tendency to seek novel solutions to problems or to find alternative methods for accomplishing a task. Low scores on this variable may be indicative of a person who is comfortable applying a ready made procedural solution to a problem, and may not seek to develop their own solution using alternative methods. Thus, the results suggest that those operators who have an overly original or non-standard approach to the manual ultrasonic task may produce more errors than those operatives who are inclined to follow a standardised procedure.
These results have implications both for the selection of new ultrasonic operatives and also for the training of existing operators. With respect to selection these results suggest that both ability test and personality scale scores can be used to select staff with appropriate characteristics for conducting ultrasonic inspections. In relation to training, the findings suggest that this should focus both on the development of ability, particularly focussing on mechanical comprehension, and on the development of self-awareness so that operators are able to recognise when they are acting in an over-cautious manner and where they might be applying procedures which are not compatible with those prescribed for the assessments undertaken.

**A6.5 Reference**

Appendix 7
PANI 3 Defect Results

Contents

Test Piece P3TP01
Test Piece P3TP02
Test Piece P3TP03
Test Piece P3TP01

The overall Flaw Detection Frequency (FDF) of this test piece was 58%

Defect 1 – Extension to land

The FDF of Defect 1 was 75%

Defect 2 - Disc Upper Toe Crack

The FDF of Defect 2 was 42%
Test Piece P3TP02

The overall Flaw Detection Frequency (FDF) of this test piece was 64%

Defect 1 – Extension to land

The FDF of Defect 1 was 62%

Defect 2 – Disc lower toe crack

The FDF of Defect 2 was 62%
Defect 3 – Variable erosion pipe lower toe

The FDF of Defect 3 was 69%
Test Piece P3TP03

The overall Flaw Detection Frequency (FDF) of this test piece was 67%

Defect 1 - Disc Upper Fusion Face LOSWF

The FDF of Defect 1 was 53%

Defect 2 - Disc lower toe crack

The FDF of Defect 2 was 73%
Defect 3 – Pipe lower toe crack

The FDF of Defect 3 was 53%

Defect 3
Test Piece P3TP03

Defect 4 – Short erosion pipe lower toe

The FDF of Defect 4 was 87%

Defect 4
Test Piece P3TP03
Appendix 8
PANI 3 Theoretical Questions

Contents

Amended version of Serco Report giving:
Answers to Theoretical Questions

Note:
As with the test piece details, in order to maintain the security of the questions, the questions were derived by the project team and were not submitted to the management committee for approval.
1 Theoretical Questions & Answers

The following pages contain the 16 theoretical questions and the ideal answers used in the PANI 3 experimental work.
Consider the defect shown in the diagram below. The weld is a single V with a fusion face of 30°. The weld cap and weld root are in the as welded state. The defect is a LOSWF defect.

Describe how you would detect the LOSWF defect.

Describe the signals you would expect to see with each probe you would use.

Write your answers below and draw diagrams as required.

60° beam on the full skip will hit the defect at normal incidence and the echo will plot out beyond the backwall. Type 2 echo dynamic.

At half skip the 60° beam will be reflected down to the backwall and back up the same path. The signal will plot out beyond the position of the defect. Type 2 echo dynamic.

A 45° beam at full skip may pick up the top & bottom tip response. Type 3b dynamic.

A 70° beam at half skip may pick up the top & bottom tip responses Type 3b dynamic.
Consider the weld geometry shown in the diagram below. The weld is a single V with a fusion face of 30°. The weld cap and weld root are in the as welded state. The weld has a concave root with the geometry shown.

Describe the signals you would expect to be generated by the root geometry when using angled shear wave probes to inspect the weld.

Describe any actions you would take to confirm the source of the echoes produced.

Write your answers below and draw diagrams as required.

45° beam will give Type 1 echo dynamic which will plot out at root.

All angled shear beams may give responses which are generated by hitting the root and reflecting up to the weld cap. These echoes will plot out beyond the backwall and can be tested by damping on the weld cap.
Consider the defect shown in the diagram below. The weld is a single V with a fusion face of 30°. The weld cap and weld root are in the as welded state. The defect is a crack originating at the toe of the weld.

Describe how you would detect the toe crack defect.

Describe any actions you would take to confirm the source of the echoes produced.

Describe the signals you would expect to see with each probe you would use.

Write your answers below and draw diagrams as required.

45° beam on the full skip will generate a corner response – Type 1 echo dynamic – which will plot out at the toe.

70° probe scanned up to the toe may detect a specular reflection direct from the toe crack. This will be a Type 1 echo dynamic but will not be maximised due to the restriction of the toe.
Consider the two defects shown in the diagrams below. The weld is a single V with a fusion face of 30°. The weld cap has been ground flush. The weld root is in the as welded state. Both the defects are vertical cracks in the middle of the weld with no tilt and no skew. One crack is rough and the other is smooth.

Describe the pulse echo techniques which could be used to detect both defects.

Describe the pulse echo signals which would be produced from the two defects.

Describe any specialised techniques which could be used to detect both defects.

Write your answers below and draw diagrams as required.

The pulse echo techniques which could be used to detect both defects are:

Specular reflection off the face using a high angle beam.

Self Tandem Technique


**Tandem**

*Obscuration technique*

*Detection of tip diffracted signals*

*Specialised techniques which could be used to detect both defects include TOFD.*
An ultrasonic inspection has been performed on the weld shown below. The weld is a nozzle geometry formed by the intersection of a small diameter pipe with a larger diameter pipe. The nozzle is set on with the weld cap and root in the as welded state. The inspection has been performed on the external surfaces of both pipes.

Your PCN Level 1 operator has reported a discrete indication at the 50° position as shown on the diagram. He is unable to establish whether it is a geometric response or a reportable defect indication.

List the steps you would go through to establish whether the indication is a geometric echo or a reportable defect.

**Identify the signal**
**Investigate Amplitude**
**Plot position**
**Look at extent around the circumference**
**Look at signal diametrically opposite**
Ultrasonic Practitioners have to be qualified prior to carrying out inspections.

Where would the qualification requirements be stated?

a) Procedures  
b) Quality Plans  
c) On drawings  
d) Contract documents

What type of qualifications (certificates) are available to Ultrasonic Practitioners?

a) Central Certification (PCN – EN 473)  
b) Employer based Certification – Companies written code of practice  
c) ASNT – ACCP  
d) European Central Certification. This is generally based on EN473
In the table below describe, for each of reflectors, the echo dynamic pattern that would be observed on the flaw detector when the probe is scanned across the defect – transverse movement – and along the defect – lateral movement.

Give an example of a weld defect which would give each type of response.

Add any other comments in the final column.

<table>
<thead>
<tr>
<th>Type of Reflector</th>
<th>Echo Dynamic Pattern</th>
<th>Discontinuity Type(s)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Reflector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smooth Elongated with no TWE</td>
<td>1</td>
<td>1</td>
<td>Pore / slag</td>
</tr>
<tr>
<td>Smooth Elongated with TWE</td>
<td>2</td>
<td>2</td>
<td>Slag line</td>
</tr>
<tr>
<td>Rough Elongated with no TWE</td>
<td>1</td>
<td>3b</td>
<td>LOSWF / Crack</td>
</tr>
<tr>
<td>Rough Elongated with TWE</td>
<td>3b</td>
<td>3b</td>
<td>Slag Line</td>
</tr>
</tbody>
</table>

Sketch the ‘Transverse Movement’ Echo Dynamic Patterns for the three type of responses listed below and on the next page:

1. Point Reflector
2. Smooth Elongated with TWE

3. Rough Elongated with TWE
The diagram below shows 3 flaws. State the NDT Methods/Techniques which could be used to compliment an Ultrasonic Inspection of the weld.

1. MPI
2. Dye Penetrant
3. Eddy Current
4. Radiography
5. TOFD

The diagram below shows a weld containing a smooth vertical flaw.

State the complimentary Ultrasonic techniques which would aid the characterisation and evaluation of the flaw.

1. TOFD
2. Tandem technique
3. Obscuration
The diagram below shows an ultrasonic probe being scanned on a curved surface towards a planar flaw. The beam axis is shown by the arrows.

Sketch the ‘A’ Scan presentations (at the same gain settings) that would be observed at positions 1 and 2.
The diagram below shows a weld with a number features.

Describe the effect that each of the features numbered 1 to 4 would have on an Ultrasonic Inspection.

1. Lamination
2. Loose Scale
3. Grainy Material
4. Internal Erosion

1. Restrict coverage by angle beams
2. Impair coupling and increase noise
3. Increased noise due to scattering of the beam
4. Distort full skip reflections as well as producing interfering echoes.

What effect would incorrect heat treatment have on an Ultrasonic Inspection?

*Cause grain growth and hence increase noise and attenuation*

What type of flaws would be produced during Stress relief?

*Reheat cracking*
The four diagrams a) to d) below show different evaluation scans used for characterisation of imperfections.

Name each scan.

For each scan describe what information about the imperfection the scan will provide.

1.1.1

a) ... SCAN

b) ... SCAN

c) ... SCAN

d) ... SCAN
a) Lateral Scan: Length extent and defect orientation and morphology in length direction
b) Depth Scan: Through wall extent and defect orientation and morphology in through wall direction
c) Swivel Scan: Information on defect skew
d) Orbital Scan: Information on whether defect is volumetric or planar
The equipment used in Ultrasonic Inspections is controlled under Company quality systems to ensure correct functionality.

Describe what checks should be made on a Flaw Detector

a) Annually?

*Full calibration*

b) Weekly?

*Linearity of the time base*
*Linearity of the equipment gain*

c) Daily?

*Sensitivity and signal to noise ratio*

Describe what checks should be made on Probes:

a) Weekly?

*Beam Profile*

b) Daily?

*Probe index*
*Beam Angle*
*Beam Alignment*

During an Ultrasonic Inspection when are Equipment Calibrations performed?

*At the start and end of an inspection and shift.*

What Documentation would substantiate the Equipment Calibrations?

*Calibration Certificates*

How would you know you were working to the correct issue of an Ultrasonic Inspection Procedure?

*Quality Plan*
Contract

Client's Documentation

Client's Order to NDT Service Company
State three methods used to set an Ultrasonic inspection sensitivity

a) DAC  
b) DGS  
c) Grain Interference Method (Grass level at 2mm screen height at maximum test range).

State three types of Reference reflectors used to set an Ultrasonic inspection sensitivity

a) Side Drilled Holes  
b) Flat Bottom Holes  
c) Rectangular Notches

In general recording levels are expressed as percentages of the reference levels.

For each of the following recording levels expressed as a % of DAC give the equivalent dB value (e.g. 50% DAC = DAC - 6dB).

a) 33% = - 10dB  
b) 20% = - 14dB  
c) 10% = - 20dB
List the information that should be included in a final inspection report.

A final report shall include the following information:-

1. Component identification and material
2. Identification of detailed test procedure
3. Stage of manufacture
4. Identity of operator and certification status
5. Date of test
6. Sketch of component configuration with dimensions
7. Type of ultrasonic flaw detector
8. Details of probe
9. Calibration and Reference blocks
10. Test sensitivity and evaluation/recording levels
11. Test limitations
12. Parent material condition
13. Test Results
The graph shown below has been plotted to calculate the Transfer Correction between a reference block (DAC Block) and the material under test.

Line A – B shows the line plotted from the reference block.

Line C – E shows the line plotted from the material under test.

Line C – D is parallel to line A – B and is separated from it by X dB.

What effect does the difference X dB represent?

*Transfer Loss due to surface*

At Position 1 on the Range axis the difference between line C – D and the line C – E is Y dB.

What effect does the difference Y dB represent?

*Attenuation in the component*
For any ultrasonic examination an examination procedure shall be established.

Explain what is meant by the “Capability of a Procedure”

*The capability of the procedure is the detection and sizing performance than can be achieved if applied correctly. i.e. the defect types and sizes which can be reliably detected and sized.*

Explain what is meant by the “Reliability of an Inspection”

*The reliability of an inspection refers to how well the procedure is applied in practice. i.e. it is the combination of the capability and the human factors influence of the operator.*

If an inspection procedure is said to be “Qualified”, what does this mean?

*The inspection procedure and equipment has been shown through analysis and tests to be capable of detecting and sizing the required defects.*

What are “Blind Trials”?

*Blind trials are trials of an operator inspecting text pieces where the operator has no knowledge of the defects, if any, contained in the test pieces.*

Why is it important to carry out an Ultrasonic Inspection in accordance with an approved/qualified procedure?

*An approved or qualified procedure will have been assessed to ensure that it is capable of achieving the required performance for the defects requiring detection. The procedure ensures that the inspection can be repeated and will achieve the same results.*
Appendix 9

Proposed Long Form Procedure Format

Note:
The pro-forma sheet in Appendix A of this procedure should be 1:1 scale. The scale has not been maintained in this copy as it is included for demonstration purposes only.
Front Sheet

The front sheet is designed to meet the following requirements:

- Clear title
- Easy recognition of the personnel qualification requirements - this could be colour coded as shown
- Early statement of equipment required
- QA signature approval and revision control.
Long Form Procedure for the Ultrasonic Inspection of PANI 3 Test Pieces Based on BS EN 1714

The examination shall only be performed by personnel, certificated to PCN Level 2 Ultrasonic Weld Testing or its equivalent in the following category(s):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1, 3.2</td>
<td>Plate and Pipe</td>
</tr>
<tr>
<td>or</td>
<td>3.7</td>
</tr>
<tr>
<td>or</td>
<td>3.8</td>
</tr>
<tr>
<td>or</td>
<td>3.9</td>
</tr>
</tbody>
</table>

**Equipment**

| Flaw Detector | A calibrated flaw detector that meets the requirements of BS EN 12668-3:2000. |
| Probes | 0° twin crystal compression, 10mm dia., 5 or 4MHz 45° single crystal shear wave, 10mm dia., 4MHz 60° single crystal shear wave, 10mm dia., 4MHz 70° single crystal shear wave, 10mm dia., 4MHz The performance of all probes shall be checked against the appropriate requirements of BS EN 12668-3:2000 |
| Calibration Block | A2/A4 blocks for time base calibration (BS EN 12223 and 27963:2000) |
| Reference Block | A reference block containing 3mm dia. SDH’s for sensitivity calibration – DAC (BS EN 583-2 Annex B). |
| Couplant | Ultragel couplant. |
| Documents | BS EN 1714 shall be available at the inspection site |

**Author**

**Level III Approval**

**Approved**

Authorised Copy No.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Amendment</th>
<th>Date</th>
</tr>
</thead>
</table>

INSPECTION VALIDATION CENTRE
Section 1 Information

This section contains collates all the information which the operator needs to do the inspection. It includes information beyond that normally included in procedures. It is designed to meet the following requirements:

- Provide the operator with an appropriate briefing about the inspection before undertaking the task
- Pass onto the operator knowledge which was used to produce the procedure - this can be used as the basis for any on the job training. Even if there is no defect mechanism predicted it can provide information on what could be detected by the scans and alert the operator to look for the unexpected
- Highlight to the operator any particular signals or features of the inspection

The information can also be used as a capability statement for the inspection with the purpose of stating for the benefit of the client the capability of the procedure.
1.0 **Information**

1.1 The aim of the inspection is to detect, locate and evaluate all recordable defect indications. Ultrasonic responses from geometric features shall not be recorded.

1.2 The geometry of the component is shown below. The weld geometry is a T-joint formed by welding a 20 mm thick disc to the inside of an 8” diameter pipe.

1.3 There is an unfused land in the weld

1.4 9 scans are to be performed. These are shown in the diagram below and listed in the table.

1.5 The positions of the defects to be detected are shown in the diagrams below, with descriptions provided.
1.6 Cracking originating at the unfused land can occur at position 1. This can be detected by Scan 1, the 0° probe from the external surface of the pipe. It is possible that the angle beams from the plate may provide an indication from such a defect.

1.7 The defect at the lower toe on the pipe can be an erosion defect which will show up with Scan 1 as a change in the position of the backwall echo. Scans 8 and 9 with the angle beams may also give an indication. Alternatively, cracking can occur at this toe and Scans 8 and 9 will then become the main detection beams.
1.8 Lack of Fusion on the vertical fusion faces will be detected by Scan 1. Scan 3, the 45° beam on the full skip will detect lack of fusion on the angled fusion face.

1.9 Toe cracks at the toes of the welds will be detected by the angle beams: Scan 6 and 7 from the pipe and Scans 3, 4 and 5 from the disc.

1.10 The geometry of the weld also produces a number of geometric echoes from the unfused land and the weld caps. Examples of less obvious geometric echoes are given below.

| Scan 3 45° beam from the plate | Scan 8 60° beam from the pipe | Disc | Pipe | 1 0° | 3 45° | 3 40° | Disc | Pipe | 6 7 60° 70° | 3 4 5 45° 60° 70° | 6 7 60° 70° | Disc | Pipe | 1 0° |
References

5.1 BS EN 12223:2000 Non-destructive testing. Ultrasonic examination. Specification for calibration block No.1

1.11 BS EN 27963:2000 Non-destructive testing. Ultrasonic examination. Specification for calibration block No.2


1.14 BS EN 583-2:2001 Non-destructive testing. Ultrasonic Examination. Sensitivity and Range Setting

1.15 BS EN 583-5:2001 Non-destructive Testing. Ultrasonic Examination. Characterisation and Sizing of Discontinuities

1.16 BS EN 12668-3:2000 Non-destructive testing. Characterisation and verification of ultrasonic examination equipment. Combined equipment.
Section 2 – Pre-requisites

This section states the necessary actions that need to be performed prior to actual scanning the component.

The example lists the actions required. QA will require objective evidence that the checks have been performed. The detail on how this is done will be defined by the NDT vendors own QA system.

Again coloured paper or ink could be used to easy identify the pre-requisites section.
2.0 Prerequisites

2.1 Ensure all equipment checks are completed prior to examination.

2.2 Weekly checks in accordance with BSEN 12668 Pt 3 are:
   a) Linearity of the flaw detector time base
   b) Linearity of the flaw detector gain
   c) Beam profile for each of the probes

2.3 Daily checks in accordance with BSEN 12668 Pt 3 are:
   d) The sensitivity and signal to noise ratio
   e) Probe index
   f) Beam Angle
   g) Beam Alignment

2.4 DAC curves for each probe shall be constructed in accordance with BS EN 583-2. For components containing more than one thickness, the DAC shall be constructed over the examination range for the thickest wall section and used for the thinner sections as well.

2.5 The scanning surface shall be free from foreign matter and the test surface shall not have a gap between the probe and test surfaces greater than 0.5mm.
Section 3 – Requirements

This section defines the actual procedure for conducting the inspection of the component. It is designed to meet the following requirements:

To state with clarity and unambiguously what the operator needs to do
To ensure the operator applies the desired methodology which will minimise the chance of error
To assist the operator perform his task

It was found during the PANI exercise that the pro-forma sheet giving a scale drawing of the cross section of the component with boxes for the required data recording was a useful aid to the operators. An image of the pro-forma (not to scale) has been included in this procedure for illustrative purposes.

However, there will still be a need to include all necessary QA information regarding equipment serial numbers, DAC data etc. This information will be subject to the NDT vendors QA system and reporting procedures and so has been omitted from this document.

Again coloured paper or ink could be used to easy identify the requirements section which the operator would need to have at the work site.
3.0 Requirements

### Actions

<table>
<thead>
<tr>
<th></th>
<th>Perform checks during calibration. Following the initial calibration of the equipment the calibration shall be checked during detection and evaluation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>At least every 4 hours.</td>
</tr>
<tr>
<td>2</td>
<td>At any time misadjustment is suspected.</td>
</tr>
<tr>
<td>3</td>
<td>After change in operator or equipment</td>
</tr>
<tr>
<td>4</td>
<td>At the end of each work shift</td>
</tr>
</tbody>
</table>

2 If a decrease of more than 2dB's in sensitivity is observed the calibration shall be corrected and all areas inspected since the previous review shall be re-examined.

3 The scanning requirements are as follows:

| S1  | 0° twin compression wave probes shall be scanned with their acoustic barrier normal to the scanning direction. |
| S2  | To ensure full coverage each scan of the probe shall be overlapped by at least 50% of the crystal width or diameter. |
| S3  | The maximum scanning speed shall not exceed 100mm/second.                                                                 |
| S4  | All recordable defect indications shall be recorded relative to the datum system appropriate to the component. This shall be referenced in the final report. |
| S5  | If any part of this procedure cannot be conformed with satisfactorily, it should be reported immediately to the IVC. |
| S6  | All the inspection scans to be completed and verified are given below. All angle beam scans shall be carried out in a direction normal to the weld. |

4 Perform scan number 1 as follows:

<table>
<thead>
<tr>
<th>Scan No.</th>
<th>Probe</th>
<th>Surface</th>
<th>Inspection Range</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 degree</td>
<td>Pipe OD</td>
<td>0 – 50mm</td>
<td>OD to ID</td>
</tr>
</tbody>
</table>

4.1 **Set the sensitivity to = 2\textsuperscript{nd} BWE 100% FSH**

4.2 Determine the material thickness of the pipe.

4.3 Examine the pipe material up to the maximum extent of the angle beam probe positions i.e. cover all parent material interrogated by shear wave probes

4.4 Plot out the weld ‘toes’ and ‘unfused land area’ on the outside surface of the pipe using the 6dB drop sizing technique.

4.5 Evaluate all defect indications ≥ 20% FSH at the examination sensitivity or any reduction in BWE to below 50% FSH.
Actions

4.6 For each indication record on the 'Inspection results' sheet (Appendix A):
   a. Length (use 6 dB drop)
   b. Width (use 6 dB or 20 dB drop)
   c. Ligament (Depth to nearest surface)
   d. Axial and circumferential Location
   e. Character (Defect Type)
   f. The maximum signal amplitude above recording threshold

4.7 Set the sensitivity to = DAC + 10dB (33%)

4.8 Scan across the area to detect possible extensions / cracking to the unfused land, lack of fusion between the pipe inside surface/disc material and erosion/corrosion of the pipe inside surface.

4.9 Evaluate all defect indications ≥ 33% DAC at the examination sensitivity

4.10 For each indication record on the 'Inspection results' sheet (Appendix A):
   a. Length (use 6 dB drop)
   b. Width (use 6 dB or 20 dB drop)
   c. Ligament (Depth to nearest surface)
   d. Axial and circumferential Location
   e. Character (Defect Type)
   f. The maximum signal amplitude above recording threshold

5 Perform scan number 2 as follows:

<table>
<thead>
<tr>
<th>Scan No.</th>
<th>Probe</th>
<th>Surface</th>
<th>Inspection Range</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0 degree</td>
<td>Top of Disc</td>
<td>0 – 50mm</td>
<td>OS to IS</td>
</tr>
</tbody>
</table>

5.1 Set the sensitivity to = 2nd BWE 100% FSH

5.2 Determine the material thickness of the Disc.

5.3 Examine the disc material up to the maximum extent of the angle beam probe positions i.e. cover all parent material interrogated by shear wave probes

5.4 Evaluate all defect indications ≥ 20% FSH at the examination sensitivity or any reduction in BWE to below 50% FSH.

5.5 For each indication record on the 'Inspection results' sheet (Appendix A):
   a. Length (use 6 dB drop)
   b. Width (use 6 dB or 20 dB drop)
   c. Ligament (Depth to nearest surface)
   d. Axial and circumferential Location
   e. Character (Defect Type)
   f. The maximum signal amplitude above recording threshold

6 Perform Scans 3, 4 and 5 as follows:
6.1 Set sensitivity to DAC + 10dB (33%)

6.2 Scan normal to the weld from the top of the disc to locate possible lack of side wall fusion, cracking (surface/embedded) or other embedded defects.

6.3 When the indication is observed during the scans determine if it is ≥ 33% DAC at the examination sensitivity.

6.4 If the indication is ≥ 33% DAC then the location along the weld shall be marked on the specimen and the approximate distance from the datum recorded on the 'Inspection results' sheet (Appendix A). No further evaluation shall be performed at this time. Scanning shall then continue until all of the scans specified have been completed.

7 Perform Scans 6, 7, 8 & 9 as follows:

7.1 Set sensitivity to DAC + 10dB

7.2 Scan from the pipe OD normal to the weld ‘toes’ as plotted on the pipe outside surface, to locate possible ‘cracking’ or erosion emanating from the weld ‘toes’ of the pipe inside surface.

7.3 When the indication is observed during the scans determine if it is ≥ 33% DAC at the examination sensitivity.

7.4 If the indication is ≥ 33% DAC then the location along the weld shall be marked on the specimen and the approximate distance from the datum recorded on the 'Inspection results' sheet (Appendix A). No further evaluation shall be performed at this time. Scanning shall then continue until all of the scans specified have been completed.

8 Perform evaluation of all indications detected in the scans 3 to 9 as follows:

8.1 All the indications (marked on the specimen and recorded on the 'Inspection results' sheet (Appendix A)) shall be evaluated in detail using the relevant probes.

8.2 For each indication record on the 'Inspection results' sheet (Appendix A)

   a. Length (use 6 dB drop)
<table>
<thead>
<tr>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>b. Ligament (Depth to nearest surface)</td>
</tr>
<tr>
<td>c. TWE (Through Wall Extent) (use max amp or 20 dB drop)</td>
</tr>
<tr>
<td>d. Axial and circumferential Location</td>
</tr>
<tr>
<td>e. Character (Defect Type)</td>
</tr>
<tr>
<td>f. The maximum signal amplitude above recording threshold</td>
</tr>
</tbody>
</table>

9 Report the inspection as follows:

6.1 Complete the details in the report pro-forma
6.2 Complete a report for each weld defect using the proforma given in Appendix A.
6.2 All criteria (13 sections) of Appendix A shall be completed for each defect detected by each probe.

All Tasks Completed

Signed…………………………….. Date……………………..
<table>
<thead>
<tr>
<th>Scan No.</th>
<th>Angle</th>
<th>Stand off</th>
<th>Range</th>
<th>Location</th>
<th>Length</th>
<th>Length sizing technique</th>
<th>TWE (height)</th>
<th>TWE (height) sizing technique</th>
<th>Ligament</th>
<th>Amplitude (dB above recording threshold)</th>
<th>Echo dynamic</th>
<th>Defect type</th>
</tr>
</thead>
</table>

**PANI 3 INSPECTION RESULTS SHEET**

**INDICATION No.:**

**Operator:**

**Date:**

**Top**

**Disc**

**Bottom**

**Scale 1:1**
Code of Conduct

Prepared for Industrial Plant Owners who require a quality output from NDT inspections

The preparation of this Code of Conduct was recommended by the “Programme for the Assessment of Non-Destructive Testing in Industry” (PANI) Management Committee in their report on the third programme of work (PANI 3). The PANI 3 project was instigated with the objective of identifying solutions which will allow industry to optimise performance and minimise the magnitude of operator variation; one solution among others was to prepare a Code of Conduct for use by industrial Plant Owners to ensure that activities which normally fall outside of the NDT Operative’s province are adequately completed and provided for in a timely fashion.

A fundamental objective of the Plant Engineer is to ensure that there is every chance the NDT inspection is carried out in such a way that the results are accurate and can be relied upon; to achieve this objective, the following list of parameters should be considered whenever an NDT inspection is to be carried out:

• Site Safety and Induction – if the NDT services are provided by a service inspection company rather than from an in-house resource, adequate time should be allowed for a Health and Safety and Site Inductions. Adequate time should also be allowed for the preparation of Method Statements and Risk Assessments; this may involve an input from both the Plant Engineer (for local knowledge) and the NDT Inspector (for NDT knowledge).

• Plant Identification and Location – it is important to ensure that the NDT Inspector is aware of the precise location and identification of the plant to be inspected; to achieve this the Plant Owner may wish to escort the Inspector to the inspection area or provide a site map; the Plant Owner should also consider component identification, datums and direction of measurements (for example - measure clockwise looking north).

• Reporting Lines – in order to satisfy Health and Safety requirements and to effect good communication, it is important that the NDT Inspector is aware of who he/she should report to in terms of safety concerns and who he liaises with regarding the inspection task to be carried out; the Inspector should also be aware of who the interim report (if used) and final report should be issued to.

• Environment – to achieve the best possible outcome and the correct result, it is important that the Inspector is not affected by adverse environmental conditions, for example, many NDT applications use lubricants and sprays and therefore, it would not be conducive to the end result for the Inspector to be working in a dusty environment. Although it may not always be practical, environmental conditions such as dust, temperature and the effects of weather conditions such as wind and rain, should be minimised whenever possible.

• Access and Lighting – in order to achieve the best possible outcome, good access should be provided for the inspector; ideally, the inspector and his equipment should be positioned in front of the component to be inspected with adequate space to carry out the task. Entry points, ladders and scaffolding etc should comply with HSE and local safety rules. Very often NDT methods require specific levels of lighting which are normally stipulated in NDT Procedures and Technique Sheets.
• Surface Flatness and Surface Finish – surface conditions will normally be specified in the NDT Procedures and Technique Sheets. The surface flatness requirement (for ultrasonic inspection) is normally expressed as a measure of deviation, for example “shall not deviate by more than ¼mm in 50mm”. Failure to comply with this requirement may lead to the ultrasonic probe’s angle of refraction changing to an unknown value. Surface finish needs to be adequate for the particular technique and this can mean that it should not be too smooth. For example, a highly polished surface (for Magnetic Particle Inspection) may lead to the background paint peeling off during the inspection, whereas, a poor quality surface finish may not remove surface/weld irregularities and could result in confusion when interpreting the results.

• Time Allowed for the Inspection – in any investigation, the time it takes to complete the investigation is governed by what is found during the investigation. Very often the time allowed to carry out an NDT inspection is determined by the assumption that everything is in place for the inspector and that there will not be any defects detected (this is rarely the case). Very often the NDT instruction requires the Inspector to size and position all defects, sometimes referenced to scaled drawings; this can be a lengthy process and adequate time should be allowed to complete this part of the inspection. As a comparison, the time allowed to ultrasonically inspect a 15” PCN weld sample is 2½ hours, probably three times the normal allocation for site applications. Additionally, the site requirements for defect sizing and positioning, imposed by NDT Procedures and Technique Sheets are usually far higher than those required by PCN.

• Certification and Plant Specific Training – There are a number of organisations in the UK and other parts of the world who provide BINDT approved training and PCN certification; success in achieving PCN will enable Inspectors to demonstrate their general competence in NDT but on occasions the Inspectors will need site specific training in order to undertake inspections on complex geometries and non-standard materials associated with specific plant items.

• Specific Defects – certification schemes, including PCN are modelled on the detection of manufacturing defects, that is to say, the defects in the test samples are artificially induced and normally represent those brought about by the manufacturing process. The majority of site inspection methodologies are developed to detect service induced defects and therefore it is important to familiarise and offer training to Inspectors so that they have the ability to detect these defects.

• Defect Specification – each NDT method and technique has particular strengths and weaknesses. The selection of the parameters in the NDT procedure and the level of rigour in establishing these parameters will depend on the type of defect being sought, the acceptance level requirements and the degree of confidence required in the outcome of the inspection. The latter will depend on the consequences of the inspection failing to meet its objectives. For these reasons it is important that the Plant Owner specifies the defect types requiring detection, the required sizing accuracy (if any), the acceptance criteria and the level of confidence required in the NDT results. It is possible to apply NDT procedures based on code requirements which may not be designed to detect specific defect types in a particular inspection. In this case there will be limitations in what defects can be detected and the Plant Owner should obtain a statement on the capability of a procedure from the NDT vendor.

• NDT Procedures and Technique Sheets – NDT Procedures can include the general requirements of an NDT Method, in which case there would be a number of associated Technique Sheets (usually one per specific application), or they may include all relevant detail necessary to carry out an inspection, without the need for technique sheets. Whilst Procedures and Technique Sheets can be prepared by any competent NDT person, it is essential that they are approved by a person qualified to
NDT Level III in the relevant method. All NDT inspections should be carried out to an approved NDT Procedure and where applicable NDT Technique Sheets.

- Facilities – it is important that the NDT Inspectors, whether they are members of staff or NDT Contractors, are given adequate facilities to enable them to complete their tasks to the customer’s satisfaction and to allow them the benefit of domestic amenities. Modern technology often allows the NDT Inspectors to electronically download NDT results to a computer, which helps to eradicate drafting errors and allows them to prepare computerised (typed) reports; gone are the days when NDT Inspectors should be expected to work from the boot of a car. NDT Inspectors should be offered basic facilities that would normally be afforded to members of staff, such as a changing room, washing/showering facilities and access to a canteen (or similar arrangements). It is implicit within the PANI report that the success of an NDT inspection is proportional to the value we place on NDT and the way the Inspector is treated.

The likelihood and consequences of failure very often determine the need for NDT inspections which contribute towards the overall assessment of the suitability of plant components. Very often, Metallurgists and other Plant Specialists make assessments, predictions and judgements on the integrity and longevity of critical plant components; these judgements are based on the accuracy and repeatability of NDT inspections, it is essential therefore that the NDT Inspector is given every opportunity to “getting it right first time”. This Code of Conduct is provided as an aide-memoire to Plant Owners who are keen to benefit from Non-Destructive Testing.
Programme for the assessment of NDT in industry

PANI 3

This report describes the work undertaken and the results obtained during the 3rd project under Health and Safety Executive’s Programme for the Assessment of NDT in Industry (PANI 3). The project was instigated with the objective of identifying solutions which will allow industry to optimise performance and minimise the magnitude of operator variation in the application of manual ultrasonic inspections. The PANI 3 project was managed on behalf of the Health and Safety Executive by Serco’s Inspection Validation Centre (IVC). In order to keep the report easy to read and assimilate, the main text gives the key information and the reader is referred to the Appendices for the supporting detail.

The project comprised of an investigation into the human factors aspects of the manual ultrasonic task and an assessment of the organisation of NDT and the NDT process (initially referred to as QA Assessment). Following a data gathering exercise which is reported in Appendix 2, experimental work was performed with the twin objectives of investigating the operators’ decision making processes and the correlation of ultrasonic performance with the operators’ scores on ability tests and a number of personality scales.

The assessment of the organisation of NDT was conducted through eliciting information from operators and NDT vendor companies and reviews of previous reliability studies and other initiatives to improve NDT reliability.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the author alone and do not necessarily reflect HSE policy.