Replacement of Radiography by Ultrasonic Inspection

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Health and Safety Executive 2005

RESEARCH REPORT 301

HSE
Health & Safety
Executive

Replacement of Radiography by Ultrasonic Inspection

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This report describes the work performed on the project “Replacement of Radiography by Ultrasonic Inspection” funded by the HSE.

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HSE BOOKS

First published 2005

ISBN 0 7176 2947 3

CONTENT

1. INTRODUCTION

This report describes the work performed on the project “Replacement of Radiography by Ultrasonic Inspection” funded by the HSE.

This thirteen months project started in April 2003. The objective was to provide guidelines on the extent to which ultrasonic testing can replace radiography for welds where radiography is currently the preferred inspection method.

The two best-established NDT methods used for volumetric inspection of welds are ultrasonic testing (UT) and radiography (RT). There are a number of parameters that influence which of the two methods is selected: technique requirement, accessibility, safety considerations, tradition, but the two most influential factors are code requirements and economics.

One of the main disadvantages of radiography is the potential hazard to health associated with the ionising radiations which are the basis of the method. Ultrasonic inspection does not have any significant inherent safety issues and therefore can be more attractive to apply than radiography. However, it is important that the associated safety and economic advantages are not gained at the expense of reduced confidence in weld integrity.

The main objective of the project was to provide guidelines on the extent to which ultrasonics can replace radiography. The project has concentrated on pulse-echo techniques. The factors influencing choice of inspection methods were considered. When the code allows either UT or RT usually the cheapest method, for that particular component, is selected. It is therefore important to consider the economic viability of ultrasonic inspection, even though HSE’s main concerns are related to health and safety aspects.

The project included the assessment of improved or mechanised ultrasonic techniques which provide records of defect images and could speed up the inspection while also improving reliability.

2. SUMMARY OF WORKSCOPE

The main aspects of the workscope were as follows:

2.1 Code Requirement

The codes most commonly used in the UK were reviewed and their requirements summarised.

2.2 Procurement of Appropriate Testsamples

Testsamples typical of those types of welds which are currently the most commonly inspected by radiography were manufactured or sourced. A range of realistic defects was incorporated such as slag inclusions, cracks, porosity, lack of fusion, and lack of penetration. Four main categories of weld were represented. These were agreed with the HSE as: small bore pipework, plates 4mm to 15mm thick, 25mm thick plate and 35mm thick pipework.

2.3 Manual Trials

Each of the samples was inspected by standard RT. Since UT and RT are different inspection methods, radiographic acceptance standards are unlikely to be applicable to ultrasonic inspection procedures. The ultrasonic techniques were therefore judged on the basis of whether they were likely to provide at least the same overall level of confidence in weld integrity.

2.4 Semi-Automated Trials

An advantage of radiography over manual UT is the production of a permanent image of defects. Semi-automated UT inspections were therefore also applied.

3. LITERATURE REVIEW

3.1 Introduction

Radiography and ultrasonics are the two generally-used, non-destructive inspection methods that can detect embedded flaws that are located well below the surface of the test part. Neither method is limited to the detection of specific types of internal flaws. However, radiography is more effective when the flaws are not planar, while ultrasonic is generally more effective when flaws are planar.

3.2 Examination by Radiography

3.2.1 General

The principle of radiography is that a source of radiation is directed towards an object. A sheet of radiographic film (or other imaging device) is placed behind the object. The density of the image is a function of the quantity of radiation transmitted through the object, which in turn is inversely proportional to the atomic number, density, and thickness of the object.

X-ray and γ-ray radiography are the two main radiographic inspection methods. The choice of which type of radiation is used (x-ray or γ-ray) depends on the thickness of material to be tested. Gamma sources have the advantage of being more portable and therefore more appropriate for site work. Portable x-ray units are also available with sources ranging in energy from 150keV to 500keV. To maintain a good flaw sensitivity, the x-ray tube voltage should be as low as possible (for the sample thickness under investigation). Also, the field inspection of thick sections can be a time consuming process, because the effective radiation output of portable sources may require long exposure times. Therefore, x-ray field inspection is generally limited to the inspection of specimens of wall thickness less than approximately 75mm.

A major disadvantage of radiography is that x-rays and γ-rays have harmful effects on the body. They are very hazardous. They can not be detected by the senses and have, therefore, legal mandatory requirements, which must be followed and strictly adhered to before and during their use. They have to be used inside a protective enclosure or with appropriate barriers and warning signals to ensure there are no hazards to personnel. Another disadvantage of radiography is that it is not a reliable method for the examination of cracks and planar type flaws. In order to detect these defects, the x or γ rays need to be directed parallel to the orientation of the defects. It has been proven than when this orientation is greater than approximately 8 degrees then the crack may not be detected. This is a particular problem for weld examination since cracks may lie at various orientations.

Compared to other non-destructive methods of inspection, radiography can be expensive. Relatively large costs and space allocations are required for a radiographic laboratory. Costs can be reduced considerably when portable x-ray or γ-ray sources are used. Operating costs can be high because sometime as much as 60% of the total inspection time is spent in setting up for radiography. With real-time radiography, operating costs are shorter and there are no extra costs for processing or interpretation of film.

Even in view of these disadvantages, radiography is the most widely used method for detection of volumetric flaws.

Radiography has advantages, such as the ability to inspect for both internal and external flaws, the ability to inspect covered or hidden parts or structures, the ability to detect significant variations in composition and the production of a permanent record or radiograph.

Traditional x-ray systems use photosensitive films to create the x-ray image. However, in film radiography, depth parallel to the radiation beam is not recorded. Consequently, the position of a flaw within the volume of the sample cannot be detected with a single radiograph.

More recent techniques such as real time radiography and computed tomography use fluorescent screens.

Real time radiography provides a two-dimensional image that can be immediately displayed on a viewing screen or television monitor. This technique converts unabsorbed radiation into an optical or electronic signal that can be viewed immediately or can be processed with electronic or video equipment. The main advantage is the opportunity to manipulate the testpiece during radiographic inspection. This capability enhances the detection of cracks and planar defects by allowing manipulation of the part to achieve the best orientation for flaw detection. Component manipulation during inspection also simplifies three-dimensional dynamic imaging for the determination of flaw location and size.

Computed tomography is another important radiological technique with enhanced flaw detection and location capabilities. Computed tomography involves the generation of cross-section views instead of a planar projection. The cross-sectional image is not obscured by overlying and underlying structures and is highly sensitive to small differences in relative density. The images are also easier to interpret than radiographs.

Two references which are particularly relevant to this project are described below.

3.2.2 Radiography of Thin-Section Welds

A study [1] was carried out by GA Georgiou and CRA Schneider on capability of radiography to detect planar defects in thin-section welds (thickness range 10-51mm). Note that there is also a related paper on radiography of thick-section welds (50-114mm), see reference [2]. The study was carried out in two parts, one with a practical approach and one concentrating on theoretical modelling and statistical analysis.

Both x-ray and γ-ray radiography were used for the practical experiments and both normal incidence and angled radiographic exposures were taken. A single-wall technique was used throughout with the Image Quality Indicators (IQI) always placed on the source side. The radiographs were evaluated 'blind' by two interpreters.

The work was carried out on 13 realistic planar defects with through-wall extent in the range 1mm to 8mm (revealed by sectioning) and length in the region of 7mm to 15mm (revealed by manual UT). The intended defect types included lack of sidewall fusion, centreline solidification cracking and HAZ hydrogen cracking. Each of these defects had a number of radiographic exposures associated with it. The specimens were radiographed under various exposure conditions, including angled shots to simulate different weld preparation angles, the use of spacer plates to simulate thicker specimens and film focus distance, etc.

The study revealed when looking at all the reported indications that more indications were reported when using x-ray radiography than gamma radiography. When the analysis was restricted to the 13 selected planar defects, only marginally more defects were reported using x-ray radiography than when using gamma radiography, but there were also a few specific cases where the opposite was observed.

The experimental results showed variations in detectability with parameters such as penetrated thickness, gape and orientation. The results correlated with the theoretical predictions.

3.2.3 Capability Statement for the Standard BEGL and BNFL Magnox Radiography Procedures

3.2.3.1 Introduction

A report on the capability of radiography methods [3] was written by British Energy. The document considers two separate radiography procedures and the implications of their application in the detection of planar defects while using the minimum source-to-film distance and worst IQI (Image Quality Indicator) sensitivities allowable in each case. The two procedures considered are the standard BEGL [4] and the BNFL Magnox [5]. Both procedures follow the stated requirements for the inspection of welds in pipes and plates according to BS EN 1435 [6]. The basis of the information reported is a review of application of the theoretical Pollitt model [7] to calculate the minimum detectable mean gape, although some relevant experimental detection results are also provided.

The Pollitt model is a mathematical model for predicting radiographic capability for smooth, parallel-sided, planar defects. The model provides useful predictions of the dependencies of detectability on such defect parameters as orientation, gape and through-wall extent. However, it only applies to idealised smooth planar slots of uniform gape and cannot be expected to accurately model real metallurgical defects which can often be rough, wavy and have variable gape.

3.2.3.2 Review of the Document

Although radiography is accepted to be generally effective for detection of all types of volumetric defects, the capability when inspecting planar defects has some restrictions, and success depends on parameters such as gape, misorientation to the radiographic beam (tilt) and through wall extent (TWE). Detection tends to be less successful as the gape of a crack becomes tighter, the orientation moves away from being parallel to the radiation source that must be applied normal to the object surface, or the through wall extent is reduced.

The Pollitt model was used to produce a set of curves that describe the minimum detectable mean gape of planar crack like defects at a range of misorientation angles. It must be made clear however that these predictions are not ideal in that accuracy relies on the simulated cracks having smooth parallel faces. Although this is rarely the case in practice, the results provide useful information on the variation in detectability as parameters such as gape, orientation and TWE are varied. In most cases the model correctly predicted the inspection capabilities that were experienced in practice.

For lack of sidewall fusion (LSF) defects in the practical exercise reported, the detection performance was poor with TWE less than 2mm. It was stated that in some cases, although the defects were detected, they were significantly undersized or misinterpreted and so considered to be missed. The largest LSF flaw to be missed had a TWE of 4mm although this had a misorientation of 45° and was in a thick weld (94mm). Another reported LSF defect missed was considered to have been due to the x-ray beam being slightly misaligned away from the required normal incidence. This requirement to achieve precise beam orientation is therefore a potential problem of radiography both in terms of inspection set-up times and missed detections.

Hydrogen crack detection was reported and although generally good, there were some misdetections and some of the smaller cracks were interpreted as linear inclusions. With transverse vertical weld metal hydrogen cracks (TVWM) in high strength Low Alloy Steel one crack with TWE of 21.8mm and misorientation of 5° and penetration 100mm was missed. There were also very tight longitudinal hydrogen cracks in carbon steel with 8.8mm TWE missed at penetrations of 75mm and 100mm.

The importance of the viewing procedure was highlighted by the fact that in a presented experimental investigation, the reported IQI sensitivity varied by up to 4 wires among the five interpreters, that were all qualified to PCN level 2. It was considered that this was due to different criteria being used when judging the last visible wire.

It is noted that radiographic inspection is most frequently employed in the inspection of new welds although is sometimes used for in-service inspections. This may be as a result of the difficulty in inspection set-up. Finally, although poor surface finish is not believed to cause a significant problem in terms of defect detection, it is considered that this is likely to result in an increased number of false calls.

3.2.3.3 Summary

It is considered that while radiographic inspections are potentially useful in performing certain non-destructive inspections, there are several limiting factors that must be taken into consideration when deciding whether or not ultrasonic inspection would provide a more reliable, cost effective and safe alternative. The measures that must be followed to ensure the safety of the inspection personnel could be considered prohibitive and the possible difficulty in detecting certain planar defects could be unacceptable. Set-up times could also be excessive in the attempt to achieve the required normal incidence of the radiation beam on the test surface and inspection result interpretation can be a time consuming and difficult process. The potential hazards associated with the exposure to the radiation by the inspection personnel must also be recognised.

3.3 Examination by Ultrasonics

3.3.1 General

Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterisation, and more.

A transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into electrical signal by the transducer and is displayed on a screen. Signal travel time can be directly related to the distance that the signal travelled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

Manual ultrasonic inspection is most common due to flexibility and cost compared to automated inspection. However, the main drawbacks of manual ultrasonic inspection are that the results of an inspection are highly dependent on the operator's skills (including, method of scanning, the identification of the indications and the interpretation of the results) and the lack of permanent data.

Semi-automated and fully automated UT systems can improve reliability.

3.3.2 Examination by Advanced Techniques

3.3.2.1 Time of Flight Diffraction (TOFD)

TOFD was originally developed to provide accurate ultrasonic flaw sizing. The technique uses the ultrasonic transit time between two probes and the flaw extremities to size the flaw. This technique is currently gaining popularity as a detection technique.

3.3.2.2 Phased–Array Technique

Phased array ultrasonics is based on the use of ultrasound probes made up of a number of individual elements that can each function separately as transmitter or receiver. Rapid electronics and advanced software are incorporated into the control and acquisition system, so that one can generate a very wide variety of different beams from one physical multi-element probe. The parameters of these beams, like angle in compression or shear wave modes, aperture and focussing properties can be set to satisfy the requirements of specific and complex inspection tasks.

3.3.3 Examination by Semi-Automatic UT and Automatic UT Inspection

The main advantage of semi- and fully- automated UT systems is that they allow the production of hard copies of the flaws detected but also provide a higher reliability and repeatability at, it most cases, higher speed. Over the years, they have become widely accepted for in-service inspection.

Recently, the acceptance of the ASME code case 2235 'use of ultrasonic examination in lieu of radiography' (see section 4.1.4) allows ultrasonics to be accepted for manufacturing inspections instead of radiography provided certain conditions are met. It would be difficult to meet these conditions without employing a semi- or fully automated system.

An example of the increasing use of automated UT is in the field of pipeline inspections. Up to ten years ago, this was the domain of radiography. With the adavent of mechanised GMAW welding, ultrasonic weld testing proved to be an effective alternative for the detection of non-fusion defects oriented unfavourably for radiography. The current state of automated ultrasonic testing has reached a level where many of the big pipeline companies are considering using UT as a replacement for conventional radiography. The main advantage of the method is that the defect can be seen in 3D rather than as a 2D radiographic image. Many defects including lack of fusion and cracks can be safely left in the weld, providing the stress engineer has sufficient information about the defect size, shape and position. A 2D image does not provide enough information for this type of decision to be made.

3.4 Radiographic against Ultrasonic NDE – Paper Review

3.4.1 Adopting European Ultrasonic Standards for Fabrications – Paper Review

The following is a summary of a relevant paper by G. Georgiou [8] on the adoption of European ultrasonic standards for fabrications.

3.4.1.1 Characterisation of Flaw Types

The characterisations of 30 flaws, from the radiography data, compared with the sectioning results are shown in Table 1.

The flaw circled in the Figure 1 below is made up of two distinct parts. The upper part is very tight and was detected using ultrasonics and characterised as threadlike (Th). Radiography detected the lower part of this flaw and was characterised it as a crack. The true nature of this flaw is a lack of fusion with some slag.

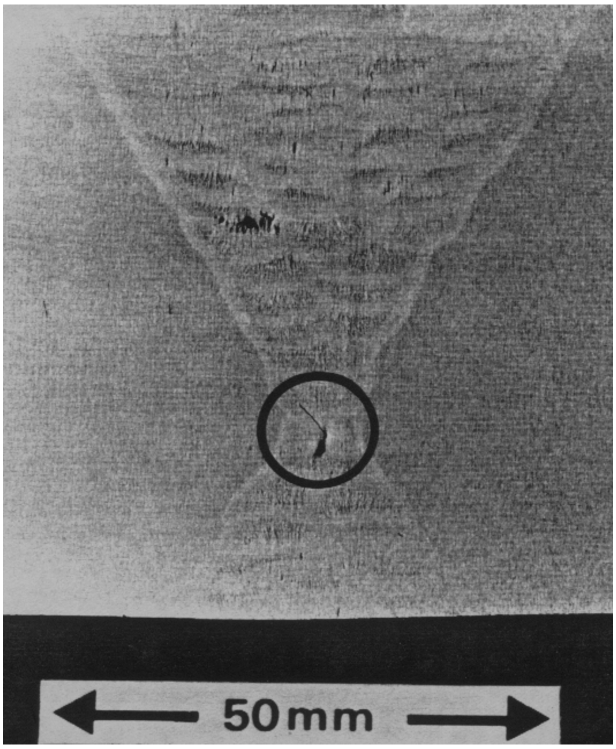


Figure 1 Slice through Crack 7, specimen 5624-19 flaw No.5

	NDT results					Sectioning results		
	Radiography		Ultrasonics					
No	Flaw type	Length, mm	Flaw type	Length, mm	Height, mm	Flaw type	Length, mm	Height, mm
1	CP 2	14	NE			Porosity	<9	2.6
2	CP 6	13	Th	23	HNM	Lack of inter–run fusion	13	0
3	CP 10	10	Is	<5	5.5	Porosity/slag	>24	5
4	Crk 1	22	Ps	30	HNM	Multiple cracks	28	4.1
5	Crk 2	35	Ps	33	HNM	Multiple cracks, Crk 2 and Crk 3 are the same flaw	38	5.7
6	Crk 3							
7	Crk 4	41	Ps	40	HNM	Lack of root/sidewall fusion	39	2.6
8	Crk 5	50	Vl	60	3.5	Slag	48	4
9	Crk 6	41	Th	57	<3	Lack of sidewall fusion/slag	43	1
10	Crk 7	41	Th	35	<3	Lack of root fusion/slag	38	5.4
11	IL 1	48	Pl	52	9	Slag	47	3.4
12	IL 2	42	M	41	3	Slag	38	3.5
13	IL 6	7	Ps	13	<3	Lack of root fusion	4	1.9
14	IL 7	6	Pl	31.5	4	Lack of sidewall fusion	16	13.5
15	IL 10	13	NE			Lack of sidewall fusion	12	0.7
16	IP 1	10	Th	23	<3	Slag/lack of fusion	10	15
17	IP 2	5	Pl	41	3.5	Multiple lack of fusion	>60	1
18	IP 3	4	Ps	8	HNM	Slag/lack of fusion	14	8.4
19	IP 4	4	Ps	23	HNM	Slag/lack of fusion	10	9.8
20	IP 5	4	Th	14	HNM	Lack of sidewall fusion	<10	0.6
21	IP 7	4	Th	18	<3	Lack of fusion	>30	1.3
22	LSF 1	65	M	87	10	Crack	63	3.5
23	LSF 2	55	M	65	13	Crack	56	5.5
24	LSF 3	55	M	71	7	Crack/porosity	44	8.5
25	LSF 4	33	M	93	25	Crack/lack of fusion/slag	46	8
26	LSF 5	24	Th	27	<3	Lack of sidewall fusion	17	4.8
27	LSF 6	22	Vl	27.5	11.5	Lack of sidewall fusion	16	10.5
28	LSF 7	12	M	107	12	Crack/slag	11	5
29	LSF 8	9	Rt	15.5	HNM	Lack of root fusion/slag	13	4.1
30	PL 1	192	NE			Lack of inter–run fusion	LNM	1.9

Table 1 A comparison of NDT and sectioning results on the first 30 flaws out of 55

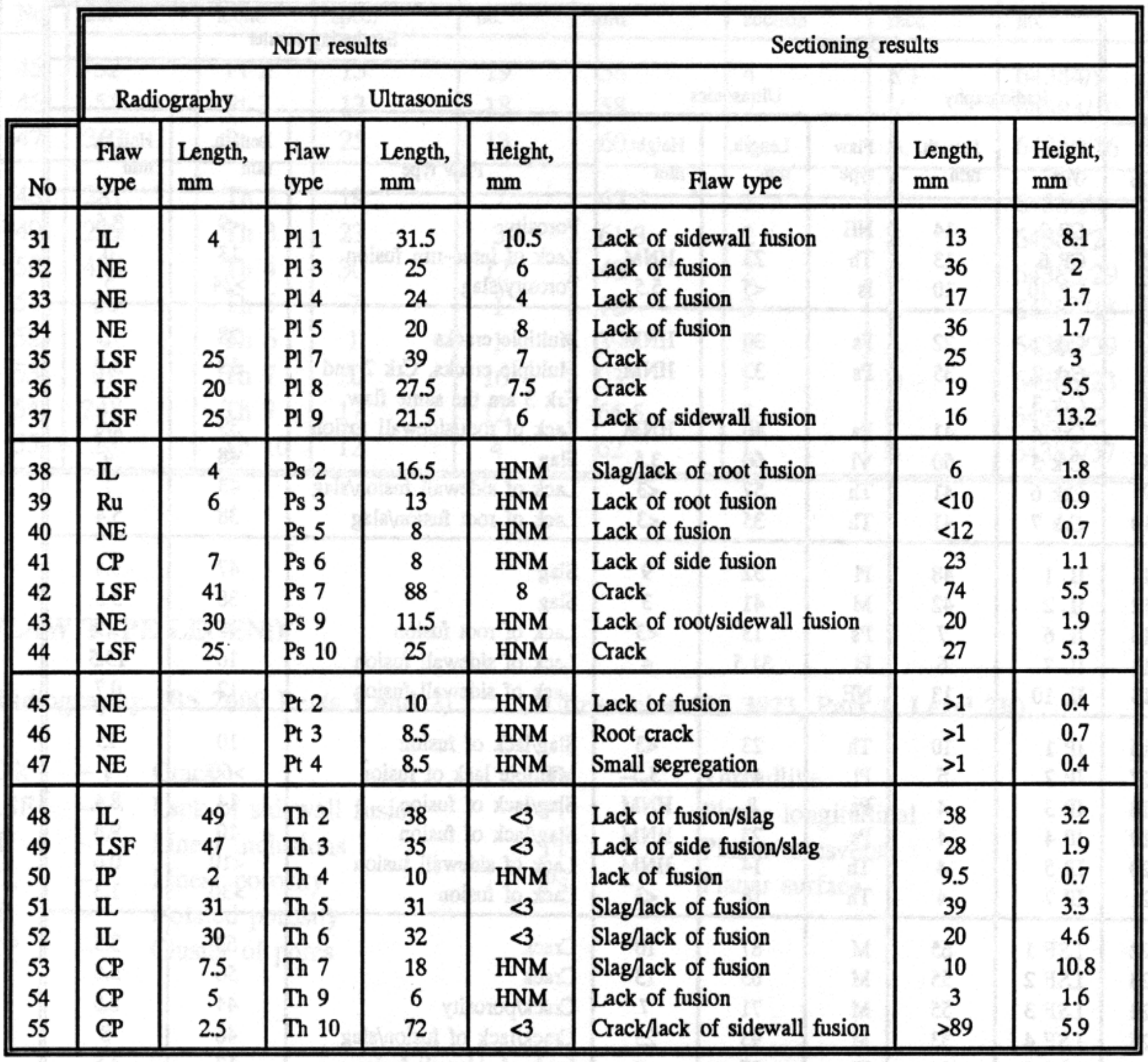
FLAW TYPE LEGEND

Radiography (BS 2600 Parts 1 and 2)

Crk	- Crack
LSF	- Lack of sidewall fusion
IL	- Linear inclusions
PL	- Linear porosity
IP	- Isolated porosity
CP	- Cluster of pores

Ultrasonics (BS 3923, Part 1, Level 2B)

Th	- Threadlike
Pl	- Planar longitudinal
Is	- Isolated
Ps	- Planar surface
Rt	- Root concavity
Vl	- Volume
M	- Multiple
NE	- Not evaluated (i.e. echo <DAC –14dB)
HNM	- Height not measurable (although attemted)
LNM	- Lenght not measurable (visible only on one slice)



	NDT results					Sectioning results		
	Radiography		Ultrasonics					
No	Flaw type	Length, mm	Flaw type	Length, mm	Height, mm	Flaw type	Length, mm	Height, mm
31	IL	4	Pl 1	31.5	10.5	Lack of sidewall fusion	13	8.1
32	NE		Pl 3	25	6	Lack of fusion	36	2
33	NE		Pl 4	24	4	Lack of fusion	17	1.7
34	NE		Pl 5	20	8	Lack of fusion	36	1.7
35	LSF	25	Pl 7	39	7	Crack	25	3
36	LSF	20	Pl 8	27.5	7.5	Crack	19	5.5
37	LSF	25	Pl 9	21.5	6	Lack of sidewall fusion	16	13.2
38	IL	4	Ps 2	16.5	HNM	Slag/lack of root fusion	6	1.8
39	Ru	6	Ps 3	13	HNM	Lack of root fusion	<10	0.9
40	NE		Ps 5	8	HNM	Lack of fusion	<12	0.7
41	CP	7	Ps 6	8	HNM	Lack of side fusion	23	1.1
42	LSF	41	Ps 7	88	8	Crack	74	5.5
43	NE	30	Ps 9	11.5	HNM	Lack of root/sidewall fusion	20	1.9
44	LSF	25	Ps 10	25	HNM	Crack	27	5.3
45	NE		Pt 2	10	HNM	Lack of fusion	>1	0.4
46	NE		Pt 3	8.5	HNM	Root crack	>1	0.7
47	NE		Pt 4	8.5	HNM	Small segregation	>1	0.4
48	IL	49	Th 2	38	<3	Lack of fusion/slag	38	3.2
49	LSF	47	Th 3	35	<3	Lack of side fusion/slag	28	1.9
50	IP	2	Th 4	10	HNM	lack of fusion	9.5	0.7
51	IL	31	Th 5	31	<3	Slag/lack of fusion	39	3.3
52	IL	30	Th 6	32	<3	Slag/lack of fusion	20	4.6
53	CP	7.5	Th 7	18	HNM	Slag/lack of fusion	10	10.8
54	CP	5	Th 9	6	HNM	Lack of fusion	3	1.6
55	CP	2.5	Th 10	72	<3	Crack/lack of sidewall fusion	>89	5.9

Table 2 A comparison of NDT and sectiononing results on the last 25 flaws out of 55

FLAW TYPE LEGEND

Radiography (BS 2600 Parts 1 and 2)

LSF -	Lack of sidewall fusion
IL -	Linear inclusions
IP -	Isolated porosity
CP -	Cluster of pores
Ru -	Undercur
NE -	Not evaluated (not seen by radiography

Ultrasonics (BS 3923, Part 1, Level 2B)

Th -	Threadlike
Pl -	Planar longitudinal
Pt -	Planar transverse
Ps -	Planar surface
HNM -	Height not measurable (although attemted)

Another interesting sample is the very long linear porosity, which was below the evaluation level according to ultrasonics; the actual length from sectioning was not measurable. According to radiography this porosity is seen virtually all along the weld.

A similar comparison of flaw detection characterisation is provided for 25 flaws in Table 2. The agreement is very good as the planar shapes (Pl), surface (Ps) and transverse (Pt) all map well in onto lack of fusion and crack type flaws. The threadlike is given this designation by ultrasonic methods because the through height was either not measurable or to be < 3 mm. For 5 out of 8 of these threadlike flaws the actual heights were confirmed from the sectioning results to be approximately ≤ 3mm (see Table 2).

3.4.1.2 Measurement of Flaw Lengths

A comparison was made between the flaw lengths using radiography and ultrasonics, with the actual flaw lengths from the sectioning results (Table 1 and Table 2). Comparisons of the mean and standard deviations of the actual flaw lengths are also made with radiography and ultrasonics, these are provided in Table 3 and Table 4.

	Measurement results	
	Radiography	Sectioning
Mean flaw length	22.7	27.7
Standard deviation	17.7	19.6
Number of flaws	45	45

Table 3 Comparison between radiography and sectioning.

	Measurement results	
	Ultrasonics	Sectioning
Mean flaw length	32.7	26.5
Standard deviation	24.3	19.6
Number of flaws	51	51

Table 4 Comparison between ultrasonics and sectioning.

Apart from the particular cases that are circled in Figure 2 and Figure 3, which clearly influenced the mean flaw length, the comparisons are good. Qualitative measures of the scatter from the ideal line in each of the above figures suggest that it is slightly greater for the case of ultrasonics than for radiography. This is expected because with ultrasonics a technique is used to measure flaw length (i.e. 6dB drop edge location for BS3923, Part 1, level 2B), in contrast to radiography where flaw length is measured directly from the radiograph.

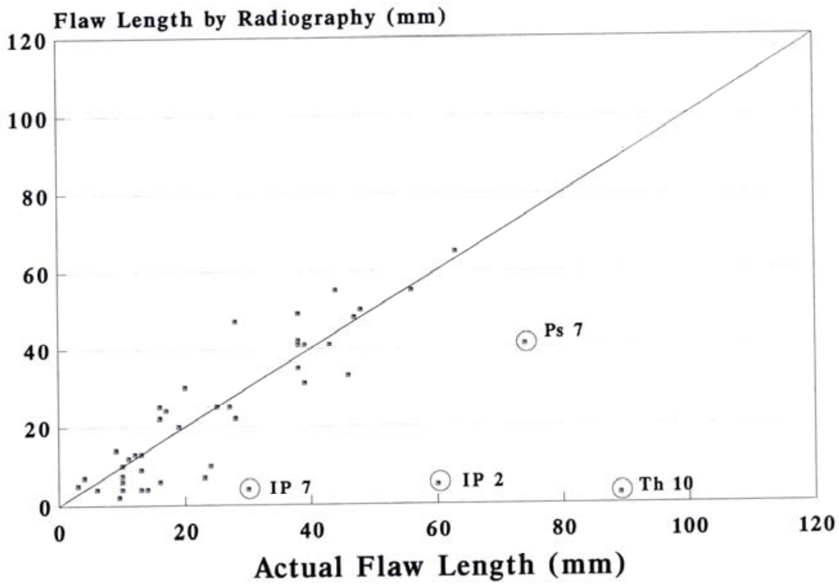


Figure 2..Comparison of flaw lengths between radiography (BS2600, parts 1 & 2) and sectioning

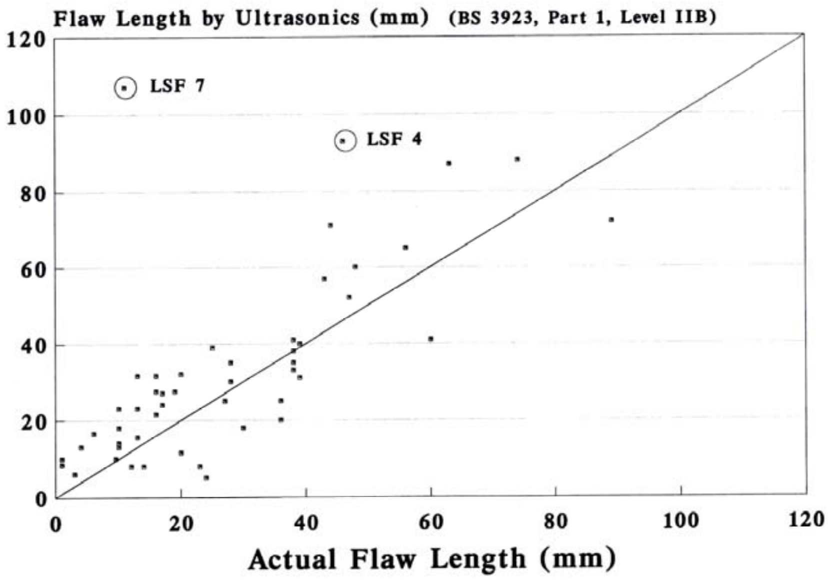


Figure 3 A comparison of measured lengths between ultrasonics (BS3923, Part 2, level IIB) and sectioning.

3.4.1.3 Measurement of Flaw Heights

From information in Table 1 and Table 2, it is also possible to compare measured flaw heights based on ultrasonics with flaw height from the sectioning results. There are 31 common cases where ultrasonics and sectioning have recorded a height measurement in both of the above tables. The cases designated 'height not measurable' under the ultrasonics column are not included. For the cases designated <3 mm, under the ultrasonic column, the measured heights are taken to be 1.5mm as this reflects the average and nearest height values recorded.

3.4.2 A Comparison of Radiographic and Ultrasonic NDE

A summary of work carried out on the comparison of radiographic and ultrasonic NDE [9] is given below.

A sufficient number of defects for a statistical analysis with three types of defects were analysed:

- Lack of fusion
- Lack of penetration
- Slag inclusions

Two operators evaluated all radiographs. Six operators examined most specimens ultrasonically. The NDE operators worked at their usual speed in an attempt to simulate usual working conditions. Samples were all plate geometry and were made of mild steel.

Results

- Lack of fusion - there was no obvious correlation between ultrasonics and radiography.
- Lack of penetration - the results appeared to confirm a lack of correlation between defect height , ultrasonic echo height and radiographic indication.
- Slag inclusions – the radiography and ultrasonic results were approximately equivalent.

4. CODE REQUIREMENT

The most commonly used codes in the UK have been reviewed and their requirements are summarised below. A more detailed review on code requirement for radiography is provided in Annex A1.

4.1 AMSE Code

The requirements and methods for non-destructive examination are contained in ASME Boiler & Pressure Vessel Code Section V. Specific requirements depending on classes and types of components are contained in Section III of the ASME code.

Section III of the ASME code is divided into 7 subsections as shown in Annex A1 Table A1.7.

For the purpose of this review the following subsections where considered:

ASME Section III Division 1 Subsection NB – Class 1 components
ASME Section III Division 1 Subsection NC – Class 2 components
ASME Section III Division 1 Subsection ND – Class 3 components
ASME Section III Division 1 Subsection NF – Supports

4.1.1 Volumetric Imperfection against Type of NDE Method

ASME V presents a table which provides general guidance on NDT capability for different types of imperfection. The table is summarised below (see Table 5).

This table assumes that only qualified personnel are performing non-destructive examinations and good conditions exist to permit examination (good access, surface conditions, cleanliness, etc.).

	Radiography (RT)	**Ultrasonic (UT)**
Service-Induced Imperfections		
Corrosion – assisted fatigue cracks	C	A
Corrosion - General	B	B
Corrosion - pitting	A	C
Erosion	A	B
Fatigue cracks	B	A
Hot cracking	B	C
Hydrogen – induced cracking	C	B
Intergranular stress-corrosion cracks	-	C
Stress-corrosion cracks (Transgranular)	B	B
Welding Imperfections		
Burn through	A	B
Cracks	B	A
Excessive/inadequate reinforcement	A	B
Inclusions (slag/tungsten)	A	B
Incomplete fusion	B	A
Incomplete penetration	A	A
Misalignment	A	B
Porosity	A	B
Root concavity	A	B
Undercut	A	B
Product Form Imperfections		
Bursts (forgings)	B	B
Cold shuts (castings)	A	B
Cracks (all product forms)	B	B
Hot tear (castings)	B	B
Inclusions (all product forms)	A	B
Lamination (plate, pipe)	-	A
Laps (forgings)	B	C
Porosity (castings)	A	C

A - All or most standard techniques will detect this imperfection under all or most conditions.
B - One or more standard technique(s) will detect this imperfection under certain conditions.
C - Special techniques, conditions, and/or personnel qualifications are required to detect this imperfection.

Table 5: Volumetric Imperfection against type of NDE method

4.1.2 Examination of Welds

Tables 6, 7, 8 & 9 summarise the requirements under ASME III for examination of welds for volumetric inspection for class 1 components, Class 2 components, Class 3 components and for supports. (See also Section 4.1.4 for conditions under which ultrasonics can replace radiography).

4.1.2.1 Class 1 Components

Category A vessel welded joints and longitudinal welded joints in other components.	All category A parts which need to be examined by a volumetric method.	**RT**
Category B vessel welded joints and circumferential welded joints in piping, pumps and valves.	All category B parts which need to be examined by a volumetric method.	**RT**
Category C vessel welded joints and similar welded joints in other components.	Category C full penetration butt welded joints in vessels and similar welded joints in other components.	**RT**
	Category C full penetration corner welded joints and similar welded joints in other components.	**UT or RT**
	Type 2 Category C full penetration corner welded fusion zone and parent metal beneath the attachment surface, after welding.	**UT**
Category D vessel welded joints and branch and piping connections in other components.	Full penetration butt welded nozzles, branch and piping connections.	**RT**
	Full penetration corner welded nozzles in vessels. If RT used: the weld fusion zone and the parent metal beneath the attachment surface, after welding.	**UT or RT** **UT**
	Full penetration corner welded branch and piping connections exceeding 4 in. nominal pipe size (DN 100) in piping, pumps, and valves.	**UT or RT**
	When weld metal builup is made to a surface: - The weld metal builup, the fusion zone and the parent metal beneath the weld metal buildup. - The full penetration butt welded joint.	**UT** **UT or RT**
	Oblique full penetration nozzles in vessels. In addition, the weld, the fusion zone and the parent material beneath the attachment surface (after welding to ensure freedom of lack of fusion and laminar defects).	**UT or RT** **UT**
	Full penetration oblique welded joint branch and piping, pumps and valves.	**UT or RT**
Special welded joints	Inertia and continuous drive friction welds - When radiographic examination is required, ultrasonic examination shall also be used to verify bonding over the entire area.	**RT and UT**
	In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electron beam welding process or by the electroslag welding process in ferritic materials.	**UT**
	When the joint detail does not permit radiographic examination. Note: The substitution of UT can be made provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the inspector as capable of detecting and locating defects.	**UT**

Table 6: Class 1 components - Parts which require a volumetric examination - Radiography (RT) or Ultrasonic (UT).

4.1.2.2 Class 2 Components

Category A vessel welded joints and longitudinal welded joints in piping, pumps and valves	Vessel welded joints when either of the members being joined exceeds 3/16 in. (4.8mm) thickness. Note that RT is not required when the thickness of each member being jointed is 3/16 in. (4.8mm) or less, magnetic particle or liquid penetrant method is used to examine the welded joint surfaces..	**RT**
	Pipe, pump and valve longitudinal butt welded joints.	**RT**
Category B vessel welded joints and circumferential welded joints in piping, pumps and valves.	Vessel welded joints when either of the members being joined exceeds 3/16 in. (4.8mm) thickness. Note that RT is not required when the thickness of each member being jointed is 3/16 in. (4.8mm) or less. Magnetic particle or liquid penetrant method is used to examine the welded joint surfaces.	**RT**
	Pipe, pump and valve butt welded joints.	**RT**
Category C vessel welded joints and similar welded joints in other components.	Full penetration butt welded joints and similar welded joints in other components when either of the members being joined exceeds 3/16 in. (4.8mm) thickness. Full penetration corner welded joints and similar welded joints in other components when either of the members being joined exceeds 3/16 in. (4.8mm) thickness. Note that RT or UT is not required when the thickness of each member being jointed is 3/16 in. (4.8mm) or less. Magnetic particle or liquid penetrant method is used to examine the welded joint surfaces and similar welded joints in other components.	**RT** **UT or RT**
Category D vessel welded joints and similar welded joints in other components.	As per Category C Except for welded branch connections and nozzles in piping, pumps and valves with nominal pipe size exceeding 4 in.	**As per Category C** **RT**
Examination of welds for vessels designed to NC-3200	Category A & B welded joints	**RT**
	Category C welded joints - Full penetration butt welded joints. - Full penetration corner welded joints - For selected corner joint constructions	**RT** **UT or RT** **UT**
	Category D welded joints - Full penetration butt welded joints. - Full penetration corner welded joints	**RT** **UT or RT**
Special welded joints	Inertia and continuous drive friction welds. Note: UT is used to verify bonding over the entire area.	**RT and UT**
	In addition to the requirements for the type of weld being examined, all complete penetration welds made by electroslag welding process in ferritic materials.	**UT**
	When the joint detail does not permit radiographic examination. Note: The substitution of UT can be made provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the inspector as capable of detecting and locating defects.	**UT**
Weld joints in storage tanks	Atmospheric storage tanks: sidewall joints and butt joints in nozzles (except for roof nozzles)	**RT**
	Welds joints in 0-15 psi storage tanks: sidewall joints, roof joints, roof-to-sidewall joints (if permitted), joints in bottoms not supported directly on grade and butt joints in nozzles.	**RT**

Table 7: Class 2 components - Parts which require a volumetric examination - Radiography (RT) or Ultrasonic (UT).

4.1.2.3 Class 3 Components

Category A vessel welded joints in vessels and similar welded joints in piping, pumps and valves	All Parts which need to be examined by a volumetric method.	**RT**
Category B vessel welded joints and circumferential welded joints in piping, pumps and valves	All Parts which need to be examined by a volumetric method.	**RT**
Category C vessel welded joints and similar welded joints in piping, pumps and valves	All Parts which need to be examined by a volumetric method.	**RT**
Category D vessel welded joints and similar welded joints in piping, pumps and valves	All Parts which need to be examined by a volumetric method.	**RT**
Special welded joints	Inertia and continuous drive friction welds - When radiographic examination is required, ultrasonic examination shall also be used to verify bonding over the entire area.	**RT and UT**
	All complete penetration welds made by the electroslag welding process in ferritic materials.	**UT**
	When the joint detail does not permit radiographic examination. Note: The substitution of UT can be made provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the inspector as capable of detecting and locating defects.	**UT**
Welded joints in storage tanks	All Parts which need to be examined by a volumetric method.	**RT**

Table 8: Class 3 components - Parts which require a volumetric examination - Radiography (RT) or Ultrasonic (UT).

4.1.2.4 Supports

Class 1 Support Welds	All full penetration butt welded joints in primary members.	**RT**
	Special requirements for weldments that impose loads in the through thickness direction of primary members 1 in. and greater in thickness, the base material beneath the weld.	**UT**
Class 2 and Metal Containment (MC) Support Welds	Special requirements for weldments that impose loads in the through thickness direction of primary members 1 in. and greater in thickness, the base material beneath the weld.	**UT**
Class 3 Support Welds	Special requirements for weldments that impose loads in the through thickness direction of primary members 1 in. and greater in thickness, the base material beneath the weld shall be ultrasonically examined.	**UT**
	Inertia and continuous drive friction welds - When radiographic examination is required, ultrasonic examination shall also be used to verify bonding over the entire area.	**RT and UT**

Table 9: Supports - Parts which require a volumetric examination - Radiography (RT) or Ultrasonic (UT).

4.1.3 Acceptance Standards

4.1.3.1 Class 1 Components

Radiography

Indications shown on the radiographs of welds and characterised as imperfections are unacceptable under the following conditions:

(a) Any indication characterised as a crack or zone of incomplete fusion or penetration;

(b) Any other elongated indication which has a length greater than (where *t* is the thinner portion of the weld):

- 1/4 in. (6mm) for *t* up to 3/4 in. (19mm), inclusive
- 1/3 *t* for t from 3/4 in. (19mm) to 2 1/4 in. (57mm), inclusive
- 3/4 in. (19mm) for *t* over 2 1/4 in. (57mm)

(c) Internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions conditions shall be unacceptable, as provided in (b) above;

(d) Any group of aligned indications having an aggregate length greater than *t* in a length of 12*t,* unless the minimum distance between successive indications exceeds 6*L* (*L* being the length of the largest indication), in which case the aggregate length is unlimited;

(e) Rounded indications (indications with a maximum length of three times the width or less on the radiograph) in excess of that shown as acceptable in Appendix VI - ASME III (the main points are given below):

- Only those indications which exceed the following dimensions shall be considered relevant.

Rounded indications size	Thickness of the weld *t*
1/10 *t*	*t* < 1/8 in. (3.2mm)
1/64 in. (0.4mm)	*t* = 1/8 to ¼ in. (3.2-6mm)
1/32 in. (0.8mm)	*t* > 1/4 to 2 in. (6-51mm)
1/16 in. (1.6mm)	*t* > 2 in. (51mm)

- The maximum permissible size of any indication shall be ¼*t* or 5/32 in. (4mm) whichever is less, except that an isolated indication separated from adjacent indications by 1 in. (25mm) or more may be 1/3*t* or ¼ in. (6mm), whichever is less. For *t* greater than 2 in. (51mm), the maximum permissible size of an isolated indication shall be increased to 3/8 in. (10mm).
- Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than *t* in length of 12*t*. The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Fig. VI-1134-2 of Appendix VI of ASME III.
- For *t* less than 1/8 in. (3.2mm) the maximum number of rounded indications shall not exceed 12 in a 6 in. (152mm) length weld. Aproportionally fewer number of indications shall be permitted in welds less than 6 in. (152mm) in length.

Ultrasonic

Fabrication

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity and location of all such imperfections and evaluate them in terms of the acceptance standards as given below:

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

- 1/4 in. (6mm) for *t* up to 3/4 in. (19mm), inclusive
- 1/3 *t* for t from 3/4 in. (19mm) to 2 1/4 in. (57mm), inclusive
- 3/4 in. (19mm) for *t* over 2 1/4 in. (57mm)

Where *t* is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterised as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

Preservice Examination

(a) Components whose volumetric examination reveals flaws that meet the acceptance standards of section XI IWB-3000 shall be acceptable. The flaws will be dimensioned and recorded in accordance with Section V Article 4 and this susection..

(b) Components whose volumetric examination reveals flaws that exceed the acceptance standards of section XI IWB-3000 are not acceptable for service and shall be repaired.

4.1.3.2 Class 2 Components

Radiography

As per Class 1 components (see 4.1.3.1).

Ultrasonic

As per Class 1 components - fabrication (see 4.1.3.1)

4.1.3.3 Class 3 Components

Radiography

The indications shown on the radiographs of welds and characterised as imperfections are unacceptable under the same conditions as for Class 1 components except for the additionanal following conditions:

(a) When a category B or C vessel butt weld, partially radiographed, is acceptable in accordance with (a) through (e) above, the entire weld length represented by this partial radiograph is acceptable.

(b) When a category B or C vessel butt weld, partially radiographed, has been examined and any radiograph discloses welding which does not comply with the minimum quality requirements of (a) through (e), one additional section at least 6 in. long for each radiograph disclosing such a defective welding, but a minimum total of two, shall be radiographically examined in the same weld unit at other locations. The location of these additional radiographs shall be acceptable by the inspector.

   i. If the additional sections examined show welding which meets the minimum quality requirements of (a) through (e), the entire weld unit represented by the total number of radiographs is acceptable. The defective welding disclosed by the partial radiographs shall be removed and the area repaired by welding. The weld repaired areas shall be radiographically examined.

   ii. If any of the additional sections examined shows welding which does not comply with the minimum quality requirements of (a) through (e), the entire unit of weld represented shall be rejected. The entire rejected weld represented shall be rewelded, or the entire unit of weld represented shall be completely radiographed and any part of the weld not meeting the requirements of (a) through (e) shall be repaired and examined radiographically. The rewelded joint shall be partially radiographed or the weld repaired areas shall be radiographically re-examined.

Ultrasonic

As per Class 1 components - fabrication (see 4.1.3.1).

4.1.3.4 Supports

Radiography

As per Class 1 components (see 4.1.3.1).

Ultrasonic

As per Class 1 components - fabrication (see 4.1.3.1) with the addition of the following:

Acceptance standard for laminar indications

Any indication detected in the base material beneath the weld which is of a laminar type is unacceptable if the indication cannot be contained within a circle having a diameter equal to one-half of the thickness of the thinner of the members joined.

4.1.4 Ultrasonic Examination in Lieu of Radiography - Case 2235-4.

Code Case 2235-4 [17] "Use of Ultrasonic Examination in Lieu of Radiography" covers Section I and Section VIII, Divisions 1 and 2. It allows ultrasonics in place of radiography for welds over 12.5mm thick in pressure vessels and boilers provided certain conditions are met.

These conditions include the use of automated computerised data acqisition with data recorded in unprocessed form with no gating, thresholding or filtering. This latter requirement appears to discriminate against pulse-echo techniques in favour of TOFD (since the recording of unprocessed data is more common for TOFD than for pulse-echo). The rationale behind this is not clear.

Another condition is the requirement to demonstrate performance on a qualification block containing at least one planar subsurface flaw, and two planar surface flaws (one if the block can be inspected from both surfaces), all oriented along a fusion face. The flaws must be no larger than the sizes defined by the acceptance criteria.

The ultrasonic recording and rejection criteria do not appear to take into account the capabilities and limitations of ultrasonics (either pulse-echo or TOFD).

For example for welds between 50mm and 75mm thick, 22 different acceptable sizes are defined, depending on aspect ratio (height to length ratio) and whether surface or subsurface. This means that for a 30mm thick weld, a 1.4mm high defect would be rejectable if its length exceeded 7mm (aspect ratio 0.2), whereas a 1.65mm flaw would be rejectable if its length exceeded 6.6mm. Even TOFD cannot in practice measure throughwall dimension more accurately than ± 1mm with any reliability, and length cannot normally be measured more accurately than ± 3mm (at best) using either TOFD or pulse-echo.

There is a requirement to size flaws in accordance with a qualified procedure, but no criteria for sizing accuracy are provided (except that for techniques which are not based on amplitude recording levels, such as TOFD, it must be demonstrated that the indicated length is at least the actual length, even though throughwall dimension is generally more important than length.)

Finally, since ultrasonic capability depends on a wide variety of parameters including defect location, shape and orientation, it is not clear why the ASME code case only requires demonstration on 3 (possibly 2) defects.

4.2 British and European Standards

Note:

- *BS EN 1435:1997* [6] 'Non-destructive examination of welded joints – Radiographic examination of welded joints' supersedes BS 2600: 'radiographic examination of fusion welded butt joints in steel' and BS 2910: 1986: 'Methods for radiographic examination of fusion welded circumferential butt joints in steel pipes'.
- *BS EN 13480-5:2002* [18] 'Metallic industial piping inspection and testing', supersedes BS 1113:1999 'Specification for design and manufacture of water-tube steam generating plant (including superheaters, reheaters and steel tube economisers)'.
- *BS EN 1714:1998* [19] 'NDT of welded joints – Ultrasonic examination of welded joints', supersedes BS 3923:1986 'Ultrasonic examination of welds – Part 1: Methods for manual examination of fusion welds in ferritic steels'.

4.2.1 BS 3923, BS EN 1714 & BS EN 1712

4.2.1.1 Methods for Detection of Internal Imperfections for Butt- and T-joints with Full Penetration

The generally accepted methods for testing of welds for internal imperfections for butt- and T-joints with full penetration are given in Table 10.

	Thickness, *t*, in mm		
Materials type of joint	$t \leq 8$	$8 < t \leq 40$	$t > 40$
Ferritic butt-joints	RT or (UT)	RT or UT	UT or (RT)
Ferritic T-joints	(UT) or (RT)	UT or (RT)	UT or (RT)
() indicates that the method is applicable with limitations. Note: Thickness, *t*, is the nominal thickness of the parent material to be welded			

Table 10: BS EN Methods of detection

4.2.1.2 Surface Preparation

In general, surface preparation for radiography is not necessary, but where surface imperfections or coatings might cause difficulty in detecting defects, the surface shall be ground smooth or the coatings shall be removed.

For ultrasonic inspection, the level of testing that can be achieved is dependent on the surface condition of the weld and adjacent parent material. All the scanning surfaces shall be free from loose scale and weld spatter and shall be of sufficiently uniform contour and smoothness that satisfactory acoustic coupling can be maintained. Surface preparation may also be needed to improve inspection coverage.

4.2.1.3 Examination Level

Four examination levels providing different degrees of rigour:

- *Examination level 1*: High integrity examination. Where the highest practical level of inspection is required.
- *Examination level 2:* Medium integrity examination. A rigorous level of examination for quality control purpose is required.
- *Examination level 3:* An economical level of examination. Not recommended for fitness for purpose applications.
- *Examination level 4:* Requirements not defined, they should be agreed by the contracting parties.

BS 3923 examination levels differ in terms of both sensitivity and number of techniques and BS EN 1714 testing levels differ only in terms of number of techniques.

4.2.1.4 Evaluation

BS 3923

Examination level	*1*	*2*	*3*	*4*
Normal beam scans	DAC + 14dB	DAC+ 8dB	DAC + 8dB	Method and level by agreement
Scans for longitudinal imperfections	Grass or at least DAC+14dB	DAC + 14dB	DAC + 8dB	
Scans for transverse imperfections	DAC+20dB	DAC + 14dB	DAC + 8dB	
Note: 3mm SDH DAC curve. + means more sensitive.				

Table 11: Scanning sensitivity level – BS 3923

BS EN 1712

Scanning sensitivity not specified. A choice of reference and evaluation levels is given:

- *Method 1*. Evaluation level: Reference level (3mm SDH DAC) -10dB (33%DAC)
- *Method 2*. Distance Gain Size (DGS) system.
  Evaluation level: Reference level – 4dB (not covered by BS 3923) and in accordance with Table 12.

		Thickness of parent material (mm)		
Nominal probe frequency (MHz)		$8 \leq t < 15$	$15 \leq t < 40$	$40 \leq t < 100$
1.5 to 2.5		-	$D_{DSR} = 2$mm	$D_{DSR} = 3$mm
3 to 5	Transvers wave	$D_{DSR} = 1$mm	$D_{DSR} = 1.5$mm	-
	Longitudinal wave	$D_{DSR} = 2$mm	$D_{DSR} = 2$mm	$D_{DSR} = 3$mm

Table 12: Reference levels for longitudinal and transverse waves for method 2 (DGS)

- *Method 3*. Evaluation level: Reference level (1mm deep rectangular notch DAC) -10dB (33%DAC).
- *Tandem testing*. D_{DSR} = 6mm (for all thicknesses)

4.2.1.5 Recording Level - BS EN 1712

- *Methods 1 & 3*: Acceptance level 2: reference level – 6dB (50% DAC)
  Acceptance level 3: reference level – 2dB (80% DAC).
- *Method 2:* Acceptance level 2: reference level
  Acceptance level 3: reference level + 4dB
- *Tandem testing:* D_{DSR} = 6mm (for all thicknesses)

4.2.1.6 Acceptance Levels – BS EN 1712

- The acceptance levels, 2 and 3, for full penetration welded joints in ferritic steels, shall be related to the testing technique (testing). Acceptance level 2 will normally require at least testing level B, and for acceptance level 3 at least testing level A. Any other relationship between acceptance levels and testing levels shall be defined by specification.
- All longitudinal and transverse indications with echo amplitudes and lengths exceeding the limits of Table 13 are unacceptable.
- Transverse indications with echo amplitudes equal to or exceeding the evaluation level shall be classified by additional ultrasonic scanning, radiography or other testing method to determine their nature. For planar indications only thise that are isolated whose length is less than 10mm are acceptable.
- Indications detected by tandem technique shall be investigated further if their echo amplitudes exceed the recording level. Additional ultrasonic scanning or radiography testing shall be carried out in order to determine the type and size of the imperfections.
- Linearly aligned and grouped indications shall be considered as continuous if they are separated by a distance, dx, of less than twice the length of the longest indication. The total combined length shall then be assessed against appropriate acceptance levels.
- For any length of weld equal to 6t, the maximum cumulative length of all individually acceptable indications above the recording levels shall not exceed 20% of this length for acceptance level 2, or 30% of this length for acceptance level 3.

	Acceptance levels 2 and 3	
	Methods 1 and 3	Method 2
$8\text{mm} \le t < 15\text{mm}$		
Indication length, l (mm)	Max. permitted echo amplitude	Max. permitted echo amplitude
$l \le t$	Reference level	Reference level + 6 dB
$l > t$	Reference level – 6 dB	Reference level
$15\text{mm} \le t \le 100\text{mm}$		
Indication length, l (mm)	Max. permitted echo amplitude	Max. permitted echo amplitude
$l \le 0.5t$	Reference level + 4 dB	Reference level + 10 dB
$0.5t < l \le t$	Reference level – 2 dB	Reference level + 4 dB
$l > t$	Reference level – 6 dB	Reference level

Table 13: Acceptance levels 2 and 3 for methods 1, 2 & 3.

4.2.2 PD 5500 – Specification for unfired fusion welded pressure vessels Section 5.6 - Non-Destructive Testing of Welded Joints

The non-destructive testing of welded joints for final acceptance purposes shall depend on the category of the component as determined by the table below, or otherwise agreed (NDT of parent plate is also required as appropriate):

Construction category	Non-destructive testing (NDT)	Maximum nominal thickness of component
1	100%	None, except where NDT method limits
2	Limited random	40
3	Visual only	13

Table 14: Construction categories – PD5500

4.2.2.1 Components to Construction Category 1

Examination for internal flaws: The full length of all type A welds shall be examined by radiographic or ultrasonic methods. The full length of all welded joints (other than fillet welds) of type B in or on pressure parts shall be examined by ultrasonic and/or radiographic methods.

4.2.2.2 Components to construction category 2

Category 2 construction shall be subjected to partial non-destructive testing. In cases where fabrication procedures require main seams to be welded at site, such seams shall be 100% examined by radiography and/or ultrasonic methods.

4.2.2.3 Choice of Non-Destructive Test Methods for Welds

The choice as to whether radiographic or ultrasonic testing is used shall be agreed between the purchaser, the manufacturer and the inspecting authority. The choice should be based on the most suitable method to the particular application and material. An important consideration is joint geometry which may have an overriding influence on choice of method. In exceptional cases, it may be necessary to employ both methods on the same seam.

4.2.2.4 Surface Condition

- *Radiography.* Surfaces shall be dressed only where weld ripples or weld surface irregularities will interfere with interpretation of the radiographs.
- *Ultrasonics*. The condition of the surface that will be in in contact with the probe shall be in accordance with BS 3923.

4.2.2.5 Acceptance Criteria

In general, the assessment of any defects in main constructional welds shall comply with the following: if the flaws do not exceed the levels specified in Table 15 & 16, the weld shall be acceptable without further action.

<table>
<tr><th colspan="2">Imperfection type</th><th colspan="3">Maximum permitted dimensions (mm)</th></tr>
<tr><td rowspan="3">Planar defects</td><td>Cracks and lamellar tears</td><td colspan="3">Not permitted</td></tr>
<tr><td>Lack of root fusion
Lack of side fusion
lack of inter-run fusion</td><td colspan="3">Not permitted</td></tr>
<tr><td>Lack of root penetration</td><td colspan="3">Not permitted</td></tr>
<tr><td rowspan="6">cavities</td><td>(a) Isolated pores (or individual pores in a group)</td><td colspan="3">$\varphi \leq e / 4$ and
φ 3.0mm for e up to and including 50mm
φ 4.5mm for e over 50mm up to and including 75mm
φ 6.0mm for e over 75mm</td></tr>
<tr><td>(b) Uniformly distributed or localised porosity</td><td colspan="3">2% by area for $e \leq$ 50mm and pro rata for greater thicknesses.</td></tr>
<tr><td>(c) Linear porosity</td><td colspan="3">Unless it can be shown that lack of fusion or lack of penetration is associated with this defect (which is not permitted) it should be treated as for individual pores in a group.</td></tr>
<tr><td>(d) Wormholes isolated</td><td colspan="3">$l \leq$ 6mm, $w \leq$ 1.5mm</td></tr>
<tr><td>(e) Wormholes aligned</td><td colspan="3">As linear porosity</td></tr>
<tr><td>(f) Crater pipes</td><td colspan="3">As wormholes isolated</td></tr>
<tr><td rowspan="5">Solid inclusions</td><td rowspan="3">Individual and parallel to major weld axis</td><td>Main butt welds</td><td>$l = e \leq$ 100mm
$w = e/10 \leq$ 4mm</td><td></td></tr>
<tr><td rowspan="2">Nozzle and branch attachment welds</td><td>Inner half of cross-section</td><td>Outer quarters of cross-section</td></tr>
<tr><td>$w = e / 4 \leq$ 4mm
$l = c / 4 \leq$ 100mm</td><td>$w = e / 8 \leq$ 4mm
$l = c / 8 \leq$ 100mm</td></tr>
<tr><td>Individual and randomly oriented (not parallel to weld axis)</td><td colspan="3">As isolated pores</td></tr>
<tr><td>Non-linear group</td><td colspan="3">As localised porosity</td></tr>
<tr><td colspan="5">Abbreviations used:
e parent material thickness. In the case of dissimilar thicknesses, e applies to the smaller thickness;
φ diameter of imperfections;
w width of the imperfections
l length of imperfections;
c mean length of the circumferential weld.</td></tr>
</table>

Table 15: Radiographic acceptance levels

Echo response height	Type of indication (mm)	Maximum permitted dimensions (mm)	
Greater than DAC	All	Nil	
50% to 100% DAC (DAC – 6dB) to DAC	Threadlike (Th) i.e. $h < 3$	Greater of $l \le e/2$ or ≤ 5	
	Volumetric (Vl) i.e. $h \ge 3$	w or $l \le 5$	
	Planar longitudinal (Pl) i.e. $h \ge 3$	Lesser of $l \le e/2$ or ≤ 5	
	Nozzle and branch attachment welds volumetric (Vl) and threadlike (Th)	Inner half of cross-section $l = c/8 \le 100$	Outer quarters of cross-section $l = c/6 \le 100$
20% to 100% DAC (DAC – 14dB) to (DAC- 6dB)	Planar surface (Ps) i.e. $h \ge 3$	$l \le 5$	
	Multiple (M)	l, w or $h \le 5$	
	Isolated (Is) i.e. $h < 3$	$l \le 5$	
20% to 50% DAC (DAC –14dB) to (DAC –6dB)	Threadlike (Th) i.e. $h < 3$	$l \le e$	
	Volumetric (Vl) i.e. $h \ge 3$	w or $l \le e$	
	Planar longitudinal (Pl) i.e. $h \ge 3$	$l \le e/2$	
	Planar transverse (Pt) i.e. $h \ge 3$	$l \le 5$	
	Nozzle and branch attachment welds volumetric (Vl) and threadlike (Th)	Inner half of cross-section $l = c/8 \le 100$	Outer quarters of cross-section $l = c/8 \le 100$
Less than 20% of DAC (less than DAC –14dB)	All	No limit	

Abbreviations used:

e	parent metal thickness. In the case of dissimilar thicknesses, e applies to the smaller thickness;
h	throughwall dimension of flaw;
w	width of the flaw
l	length of flaw;
c	mean length of the circumferential weld.

Table 16 Ultrasonic acceptance levels applicable to ferritic steels and weld metals in the thickness range 7mm to 100mm inclusive

There appear to be inconsistencies and errors in these PD5500 acceptance criteria. For example:

i. Echo response height of 20% to 100% DAC corresponds to (DAC – 14dB) to DAC , not to (DAC – 14dB) to (DAC – 6dB)

ii. For indications between 50% and 100% DAC in nozzle and branch attachment welds, the maximum permitted length of c/6 for volumetric and threadlike defects in the outer quarters of the cross section, is greater than permitted (c/8) in the inner quarters. This is contrary to the expectation that defects nearer the surfaces will be of greater structural concern than those further from the surfaces. This maximum dimension of c/6 is also more relaxed than corresponding defects which provide lower amplitude signals between 20% and 50% (maximum permitted length c/8). Note that in the previous 2000 issue of PD5500, the corresponding figure was c/16 not c/6. Possibly there has been a typographical error.

iii. There are rejection criteria for planar transverse indications which provide responses between 20% and 50% DAC, but no reference to planar transverse indications which provide higher responses between 50% and 100% DAC.

It should also be noted that in several cases maximum permitted indication length is 5mm (sometimes smaller for thicknesses below 10mm). In practice it is likely to be very difficult to measure the length of a defect with sufficient accuracy to determine whether the defect is below this permitted maximum.

4.2.3 Metallic Industial Piping Inspection and Testing - BS EN 13480 Part 5: Inspection and testing (Supersedes BS 1113:1999)

4.2.3.1 Surface Condition and Preparation for NDT

The following criteria should be met:

- RT: surface dressing is required where ripples or weld surface irregularities will interfere with the interpretation of the radiographs;
- UT: surface dressing is required where the surfaces in contact with the probe prevent the scanning process.

4.2.3.2 Selection of NDT Method

Depending on wall thickness, type of weld and type of material, the NDT method shall be selected according to Table 17.

Material and type of joint	Parent material nominal thickness (*e* in mm)			
	$e < 8$	$8 \leq e < 15$	$15 \leq e < 40$	$e \geq 40$
Ferritic butt joints	RT	RT or (UT)	RT or UT	UT or (RT)
Ferritic T-joints	RT	RT or (UT)	RT or UT	UT or (RT)
Austenitic butt joints	RT	RT	RT or (UT[a])	UT[a] or RT
Austenitic T-joints	RT	RT	RT or (UT[a])	UT[a] or RT
Note when two techniques are shown, the least preferred is shown between brackets. [a] UT_D (in accordance with EN 1714:1998, class D requires a specific written instruction.				

Table 17: Selection of NDT techniques for detection of welding imperfections (volumetric testing in full penetration joints, based on EN 12062:1997.

Table 18 provides the method and acceptance criteria for the NDT technique.

NDT technique	Method	Acceptance criteria
Radiographic testing (RT)	EN 1435:1997, class B [a, b] See Annex A2.	EN 12517:1998 Acceptance level 2 and additional requirements of Table A2.6, Annex A2.
Ultrasonic Testing (UT)	EN 1714:1998, class B [b] See sections 4.2.1.1 to 4.2.1.4	EN1712:1997, [c] Acceptance level 2 [d] See section 4.2.1.6
[a] However, the maximum area for single exposure shall correspond to the requirements of EN 1435:1997, class A. [b] Class A for material 1.1, 1.2, b8.1 when piping class is I or II [c] For the characterisation of indications EN 1713 may be used. [d] Acceptance level 3 for material group 1.1, 1.2, 8.1 when piping class is I or II.		

Table 18: NDT techniques, method, acceptance criteria.

4.2.4 Conclusions

ASME code: although the code stipulates that both RT and UT can be used under ASME V, RT is favoured in most cases. The Code Case 2235-4 “use of ultrasonic examination in lieu of radiography” allows ultrasonic examination in lieu of radiography provided certain conditions are met (see Section 4.1.4).

The choice as to whether radiographic or ultrasonic testing is used under the BS EN is more relaxed. The requirements impose (PD 5500) or strongly recommend the use of RT for sample of thickness of 8mm and below. For the other thicknesses above 40mm, the standards strongly recommend the use of UT. The choice shall be agreed between the purchaser and the inspecting authority. The choice should be based on the most suitable method to the particular application and material. In exceptional cases, it may be necessary to employ both methods on the same sample.

5. EXPERIMENTAL STUDY

5.1 Testsamples

The type of sample to be used for this project were identified at the beginning of the project and agreed with the HSE. The samples were to be representative of welds commonly inspected by radiography. The samples contain defects such as: lack of fusion, cracks, slag, porosity and inclusions.

The originally proposed samples included: small bore pipework, plates 25 mm thick and pipework 35 mm thick. Inspection on small thickness plates was also included.

The samples listed in Table A2.1 & Table A2.2 (Annex A2) were manufactured for the study. All the samples have single-sided welds. All samples originally had undressed cap and roots, but in some cases, additional inspections were performed after dressing the cap.

Note that the samples PL8227, PL8228, the six small bore pipes (samples P8239 to P8244) and the 35mm thick pipe P8301 were all “standard” testpieces designed for training in radiography. The defects manufactured in these samples were designed to be detectable by radiography. All the other samples contain defects which were not designed to favour either RT or UT.

5.2 Manual Inspection

5.2.1 Inspection Technique & Procedure

5.2.1.1 Radiography

The samples were subjected to radiography, the radiographs and reports were provided with the samples.

The samples were radiographically tested in accordance with the test conditions summarised in Table 19. The radiography was performed via the testsamples manufacturer and an independent radiographic inspection company.

The main choice of radiation source was decided to be x-rays, as x-rays are generally the preferred source of radiation wherever feasible e.g., for in-manufacture inspection. Portable x-ray units can be use to inspect specimens of thickness up to 65mm. As x-ray equipment is not always available or practical to use on site, it was decided that some specimens would also be γ-rayed. As Ir^{192} is one of the most commonly used sources of radiation on site for the thicknesses of interest, it was selected as the gamma source of radiation which would be used for the study.

The choice of isotope should be governed by the penetrated thickness of the material. Ir 192 was chosen as source of radiation for all the samples for which γ–ray was carried out. However, for the small thickness samples and according to BS EN 1435, Ir 192 is suitable for thicknesses over 20mm (or down to 10mm by special agreement with the customer). Some radiographic procedures permit the use of Ir 192 down to 10mm thickness provided C3 film system class is used. Sources such as Se75 or Yb169 could have been used for the γ-ray inspection of the thin material or as stated before, a finer grain film such as a film system class C3 film could have been used.

However, the radiographs provided for the undressed thin plates were carried out to class A which is the normal industry working condition (note class B is a better film system class than class A). The radiographs achieved class B sensitivity but could not achieve that of a class B for the film combination used.

The radiographs provided for the dressed thin plates were carried out to class B (better films type used: C3/C4, higher densities and class B sensitivity were achieved).

Only normal incidence radiographic exposures were taken on all the samples. A single-wall single-image technique or a double-wall single-image technique was carried out as identified in Table 19. The Image Quality Indicators (IQI) were placed on the source/film side and the visible wire numbers recorded. These compared against the required wire numbers to class A/B of BS EN 143 tables.

The radiography of the two 35mm thick pipes P8301 and PTF8 were carried out one with x-rays and the other with γ-ray, respectively. At an early stage of the project, it was decided that that x-ray inspection was the preferred source of inspection for in-manufacture inspection which explains why pipe P8301 was x-rayed. However, γ-ray would have been the preferred form of inspection on site mainly because of the reduced number of shots needed. The use of γ-rays can “flatten out” the density difference on the radiograph and therefore can reduce the number of exposures as there is a larger weld coverage for each shot needed and the associated exposure times. It was therefore decided that the later manufactured pipe (PTF8) would be γ-rayed so as to be representative of a site inspection.

An independent inspector provided additional examination of some of the radiographs when discrepancies were observed between the radiographic results and the expected results provided by the testsamples manufacturer or to check questionable UT results. Moreover, a level 3 radiographic inspector (refered to as inspector 2 in Annex A4.2) examined the three series of radiographs carried out on the four thin plates (including X-ray radiographs on the plates dressed and undressed and γ-ray radiographs on the plates undressed).

	Samples		Radiation source/ Isotope	Technique	Exposure	Sensitivity film side/ source side	Density	Film Type	Focal spot size	Sizing & Reporting Criteria	FFD/SFD
	Reference	Thickness									
Small bore	P8239 P8240 P8241 P8242 P8243 P8244	5mm 5mm 4mm 4mm 6mm 6mm	X-ray	DWSI	150Kv 150Kv 145Kv 145Kv 155Kv 155Kv 16Ma mins	wire 14 wire 14 wire 14 wire 14 wire 14 wire 15	1.5-2.2 1.6-3.0 1.6-3.5 2.0-3.5 2.1-3.2 2.0-3.2	AGFA D7	2.3x2.3	SI/08/88	750mm
Plate	2557-001	4mm	X-ray	SWSI	165Kv 4.2Ma mins	wire 15/ wire 15	2.7	FUJI IX100 (10x40)	2x2	BSEN1435	600mm
			X-ray on sample dressed	SWSI	130Kv 24Ma mins	wire 16 and 17	2.2-3.5	FOMA R4 (equivalent to AGFA D4)	0.8x0.8	SI/08/88	650mm
			γ-ray/ IR192	SWSI	142Ci mins	wire 12/ wire 12	2.6	FUJI IX80 (10x40)	2x1.5	BSEN1435	600mm
	2557-002	8mm	X-ray	SWSI	180Kv 5Ma mins	wire 15/ wire 14	2.5	FUJI IX100 (10x40)	2x2	BSEN1435	600mm
			X-ray on sample dressed	SWSI	160Kv 14Ma mins	wire 14 and 15	2.3-3.5	FOMA R4 (equivalent to AGFA D4)	0.8x0.8	SI/08/88	650mm
			γ-ray/ IR192	SWSI	152Ci mins	wire 12/ wire 12	3.0	FUJI IX80 (10x40)	2x1.5	BSEN1435	600mm
	2557-003	10mm	X-ray	SWSI	210Kv 5.4Ma mins	wire 15/ wire 14	2.5	FUJI IX100 (10x40)	2x2	BSEN1435	600mm
			X-ray on sample dressed	SWSI	175Kv 16Ma mins	wire 14 and 15	3.0-3.5	FOMA R4 (equivalent to AGFA D4)	0.8x0.8	SI/08/88	650mm
			γ-ray/ IR192	SWSI	160Ci mins	wire 12/ wire 12	2.7	FUJI IX80 (10x40)	2x1.5	BSEN1435	600mm
	2557-004	12mm	X-ray	SWSI	210Kv 6.7Ma mins	wire 15/ wire 14	2.5	FUJI IX100 (10x40)	2x2	BSEN1435	600mm
			X-ray on sample dressed	SWSI	190Kv 16Ma mins	wire 14 and 15	2.3-3.5	FOMA R4 (equivalent to AGFA D4)	0.8x0.8	SI/08/88	650mm
			γ-ray/ IR192	SWSI	175Ci mins	wire 12/ wire 11	2.7	FUJI IX80 (10x40)	2x2	BSEN1435	600mm
	TPF7	15mm	X-ray	SWSI	210Kv 10.8Ma mins	wire 14/ wire 14	2.7-2.9	FUJI IX100 (10x40)	2x2	BSEN1435	600mm
			γ-ray/ IR192	SWSI	180Ci mins	wire 12/ wire 12	3.0-3.1	FUJI IX80 (10x40)	2x2	BSEN1435	600mm
	PL8227 PL8228	25mm	X-ray	SWSI	220 Kv 42Ma mins	Wire 12	2.4-3.5 2.5-3.2	AGFA D7	2.3x2.3	SI/08/88	1000mm
Pipe	TPF6	12.5mm	X-ray	DWSI	210Kv 30Ma mins	wire 12/ wire 12	2.5-3.0	FUJI IX100 (10x40)	2x2	BSEN1435	Contact
			γ-ray/ IR192	DWSI	165Ci mins	wire 12/ wire 12	2.5-3.0	FUJI IX80 (10x40)	2x2	BSEN1435	Contact
	TPF8	35mm	γ-ray/ IR192	DWSI	600Ci mins	wire 10 fim side	2.5-3.0	FUJI IX80 (10x40)	2x2	BSEN1435	Contact
	P8301	35mm	X-ray	SWSI	155Kv 115Ma mins	Wire 14	1.8-3.0	AGFA D7	2.3x2.3	SI/08/88	1000mm

Table 19: Radiographic test conditions
(specifications given for as welded samples except when specified)

5.2.1.2 Ultrasonic

The inspection was carried out from the upper surface only.

Scanning sensitivity was set by plotting a DAC curve on side drilled holes. Hole diameter was 3mm except for the small bore pipework specimens for which a contoured DAC block with 1.5mm diameter holes was used and for the thin plates (4mm and 8mm thick) for which a flat DAC block with 1.5mm diameter holes was used. The gain was increased by +14dB for scanning. All detectable defect indications were recorded regardless of amplitude.

A range of different probes were used so that the optimum techniques could be identified. The main probes used for the ultrasonic inspection were:

- 45°, 2MHz, Ø10mm single crystal probe (not used for small thicknesses)
- 45°, 4MHz, Ø10mm single crystal probe
- 60°, 2MHz, Ø10mm single crystal probe (not used for small thicknesses)
- 60°, 4MHz, Ø10mm single crystal probe
- 70°, 2MHz, Ø10mm single crystal probe (not used for small thicknesses)
- 70°, 4MHz, Ø10mm single crystal probe

Two contoured probes were used for the inspection of the small bore pipes:

- 70°, 4MHz, Ø10mm single crystal contoured probe
- 70°, 4MHz, Ø10mm twin crystal contoured probe

Sub-miniature probes were also used to improve inspection volume and detectability where appropriate:

- 45°, 4MHz, 6x6mm single crystal probe
- 60°, 4MHz, 6x6mm single crystal probe

The inspection of the whole weld body of the small thickness samples (<10mm thick) could not be achieved due to the presence of the weld cap. Therefore, two sets of data are provided: one with the weld cap undressed and one with the cap dressed.

In most cases, only one operator carried out the inspections, with the exception of the inspection of the small thickness sample 2557-003 (10mm thick) and sample 2557-004 (12mm thick) for which the inspections were carried out by two inspectors. These two plates were examined by two operators in order to provide some information on the influence of operator on inspection detectability and on the repeatability of results. Note however that the inspections were not "blind", i.e., the inspectors had prior information on the intended defects.

5.2.2 Experimental Results

The schematics of the samples and the results are given in Annex A4. (Note that only the highest ultrasonic responses are provided in this report).

5.2.3 Discussion

It should be noted in the discussion which follows that defects dimensions generally refer to intended dimensions since very limited sectioning was performed. However, this was not considered a major disadvantage for this project since radiography does not measure throughwall dimensions. The discussion and conclusions would therefore be unlikely to change significantly even if accurate defect dimensions were known.

5.2.3.1 Small Bore Samples

Both UT and RT inspections of the specimens were carried out with and without the weld caps removed.

All the defects were reported by RT with and without the weld caps, although this was not surprising since these types of samples were designed to be used as radiographic training/examination specimens. The lack of root fusion of sample P8240 was reported to be not clearly visible on the radiograph.

The tungsten inclusions in P8239 were reported by UT when the cap was undressed but not reported when the cap was dressed. The indication reported may have been due to the geometry of the cap (the defect being very close to the cap) or the defect may have been partly removed with the cap. The radiograph of the sample done after the weld cap had been removed was examined and the radiograph analyst confirmed that the inclusions were still present.

The tungsten inclusions in the other samples were not reported with UT (with or without the weld cap being dressed).

Porosity were not always detected with UT. The removal of the cap allowed the detection of some of the defects not detected otherwise.

Overall, there was no clear benefit in dressing the weld cap, with some defects becoming more detectable and others less so.

5.2.3.2 Plates

Two types of radiography, x-rays and γ-rays, were carried out on five of the plates that is, plates 2557-001/002/003/004 (referred to as thin plates in the rest of the report) and plate TPF7. A series of x-rays radiographs were also produced for the four thin plates when the weld cap was removed.

With the exception of TPF7, the x-ray results showed improved detection capability compared to the γ-ray results although defects were still missed.

Thin plates

Only one of the sixteen intended defects in the thin plates was detected by γ-rays (centreline crack characterised as lack of fusion in the 12mm thick sample) when the first inspector carried out the inspection. The inspection of the radiographs by the second inspector (inspecteor 2) provided slightly more information. Three defects were reported at positions corresponding to intended defects location, they are: linear pores associated with a slag line, a root undercut and a lack of fusion. Defect No4 (crack) in the 12mm thick plate was correctly reported.

The radiographs provided for the four thin plates dressed were of better quality. The radiographs were done to class B (using films type C3/C4, higher densities and class B sensitivity were achieved). The following paragraphs concentrate on the x-ray radiographic results.

Sample 2557-001 (4mm)

The first radiograph inspector reported two out of the three centre line cracks of the thin plate undressed, as linear porosity and one was not reported by x-ray radiography. He also failed to report the lack of sidewall fusion defect. The report by the second inspector was similar except that he characterised the defects as linear porosity associated with lack of fusion.

The analysis of the x-ray radiographs of the dressed sample by inspector 2 revealed four cracks.

The UT results on this 4mm plate show that *a*ll the defects were above the BS 3923 reporting threshold (above 20% DAC) from either side of the weld, with the exception of a LOSWF (defect No3) which was only reported from one side of the weld.

Sample 2557-002 (8mm)

The x-ray report of the undressed 8mm thick plate by the inspector 1 shows that one of the four defects was reported as linear porosity (centre line crack), the two lack of side wall fusion defects were missed and the side wall crack (defect No4) was reported as suspected LoSWF. Inspector 2 reported three out of the four defects. Defect No1 which is a lack of sidewall fusion very close to the upper surface was reported as a missed cap edge, defect No2 (centre line crack) was reported as a crack associated with porosity and defect No4 which is a sidewall crack was reported as a lack of side wall fusion.

The radiographic results from the dressed sample did not provide more information than provided at the undressed stage by the inspector 2.

The UT inspection detected all the defects with an amplitude above 20% DAC (generally much higher) from either side of the weld.

Sample 2557-003 (10mm)

The plate contained four cracks one of which is smooth (defect No3).

Only one defect was reported from the undressed plate by both radiograph inspectors. This defect (defect No2) was characterised as linear porosity by inspector 1 and pores associated with lack of fusion by inspector 2, instead of as a centre line crack.

The radiographic results from the dressed sample reported two defects, defect No2 and another defect characterised as slag/LoF. This last defect corresponds to the location of defect No1 which is a centre line crack.

The UT was carried out by two inspectors with the same 4MHz probes. All the defects were detected regardless of the inspection side or the probe used by inspector 2. The results from inspector 1 were systematically of lower amplitude. However, both inspectors would have reported all the defects. Complementary work on the plate was carried out using 2MHz probes. The 2MHz probes provided unexpectedly better results for a 10mm thick sample. The 2MHz 70° single probe and the twin 70° 4MHz probes provided the best results overall.

Sample 2557-004 (12mm): Inspector 1 only reported one defect out of four from the undressed plate (defect No2), either by x-rays or γ-rays, as a lack of sidewall fusion but it is a tilted centre line crack. The results do not reflect what was expected. Defect No4 is an untilted centre line crack which according to the theory should have been the easiest defect to detect. The results from inspector 2 show the detection of a centre line crack (defect No4) as well as defect No2.

The radiographic results from the dressed sample reported two defects, defect No2 as above and another, defect No3 correctly characterised as a lack of fusion. The crack reported by inspector 2 from the undressed plate was not reported from the radiographs of the dressed plate.

The four defects were reported with UT by both inspectors with all the probes from either side of the weld and with amplitude above 40%DAC (generally much higher).

Other plates

The results from the two radiographic techniques on 14mm thick plate TPF7 are very similar (the x-ray inspection detected more porosity). Two out of the four defects were correctly identified, but reported with a shorter length. One defect was reported but wrongly identified (reported as a cavity instead of a slag). However, the LoSWF was not reported with either of the techniques. Regarding UT, as expected, Defect No1 (toe crack) was only detected from side B (the defect side). Defect No2 (small LoSWF close to the root) was not detected using the 45° probes. However, all the defects would have been detected if either a 60° or 70° probe was used, provided inspection was from both sides of the weld. The best responses were acheived using the 2MHz, 70° probe.

The two 25mm thick plates PL8227 and PL8228 were both radiographed using x-rays only. All the defects were reported by RT although this was not surprising since these types of samples were designed to be used as radiographic training/examination specimens. The ultrasonic results show that the 45° and the 60°, 4MHz probes are capable of detecting most defects and the stronger signals were generally obtained when scanning from the same side as the defect. The 4MHz probes were, in general, capable to detect the defects better than the 2MHz probes, this is possibly due to the better resolution and narrower beam of the higher frequency. Porosity was very difficult to detect (better at 4MHz than 2MHz as expected).

5.2.3.3 Pipes (excluding small bore)

All the defects from sample P8301 were reported by x-ray radiography (again this is as expected since it was designed as a radiographic specimen). However, the two lack of root fusion defects were not clearly defined by RT.

Three out of the eleven defects from sample P8301 are non-planar defects, including: one slag, porosity and one tungsten inclusion. These three defects were not always detected by UT and when they were, the amplitudes recorded were relatively low and sometimes close to or below the 20% DAC report threshold of BS 3923. Planar defects such as lack of fusion and cracks were all detected with amplitude more than 100% DAC by at least one of the probes used from at least one side of the weld.

However, the results show that inspection from both sides of the weld is needed as defects such as toe cracks could have been missed depending on beam angle.

The two other pipes examined, PTF6 and PTF8 were not manufactured as radiographic specimens. The results from these samples show some discepency between the expected results and the experimental results.

Pipe PTF6 (12.5mm wall thickness) was assessed using x-rays and γ-rays. The results from the two techniques are identical. Two out of the ten defects were not reported. Both of these defects are LoSWF. Three of the defects reported were not characterised as expected.

Two of the defects, that is, defect No4 (porosity) and defect No10 (root undercut) would have probably not been reported using UT, as not only were they rarely detected but when detected, the amplitude of the signals were very low. All the other defects should have been reported assuming that the access was not limited and that the inspection was performed with at least two probe angles. As expected (undressed weld cap and inspection up to full skip), the stronger signals were generally obtained when scanning from the same side as the defect. The 70° 2MHz probe provided the best results.

As an x-ray inspection of the PTF8 (35mm wall thickness) pipe was unlikely to be carried out on site, it was decided to only carry out a γ–ray inspection. The technique used was a double wall single image technique which would have probably been the choice if the inspection was carried out on site. Five shots were required to cover the full surface of the sample.

The radiographic results from the PTF8 pipe show that only five defects out of eleven were detected two of which were not characterised as expected (both should be rough planar defects, one was characterised as pores the other as a slag). Neither of the two LoSWF (defects No1 & No2) was detected. A crack adjacent to the expected position of defect No9 (crack) was reported. A second examination of the radiograph by a different operator provided results closer to expected one (note that neither of the operators knew the presence or details of the defects). Defect No6 (lack of inter-run fusion) was not reported by radiography but the UT technique also failed to detect the defect. The amplitude of the ultrasonic signal from defect No2 (LoSWF which was not reported by radiography) was relatively low with most of the probes used. As expected defect No4 (HAZ crack) was only detected from one side of the weld. Access from both sides of the weld would have been needed. The 60° and 70° 2MHz probes provided, in general, the best results.

5.2.4 Summary of Experimental Results

- Porosity, slag and tungsten inclusions were difficult to detect using UT techniques. The porosity and slag was more readily detected using 4MHz probes than 2MHz probes.

- Planar defects such as lack of fusion and cracks have all been detected using UT from at least one side of the weld, the exception being a small (2mm x 5mm) lack of inter-run fusion defect oriented parallel to the weld cap.

- The weld cap of small thickness samples may require to be dressed to allow full coverage of the weld by UT.

- Planar defects detection using UT was more difficult for inner defects adjacent to an undressed root, which made signal analysis difficult.

- RT provides better results for non-planar defects.

- RT missed some of the planar defects not specifically manufactured for radiographic inspection.

- The radiographic results of the thin plates show that x-rays provided better results than gamma-rays but also highlighted that the results can be highly dependant on the film quality (density and sensitivity achieved) and also on the ability of the analyst to interpret the radiographs. The removal of the weld cap together with the better quality of the radiographs permitted the detection of additional defects.

- Some of the results with RT and UT are unexpected and this may be related to the fact that the defects are deliberate manufactured defects.

5.3 Semi-Automatic Inspection

5.3.1 Introduction

Conventional manual ultrasonic examination requires the operator to make instantaneous interpretations and decisions on the dynamic A-Scan information that is presented during inspection. This is a task requiring great skill on the part of the operator and consequently the reliability of the inspection depends on the level of that skill. The PANI exercises [24] have clearly demonstrated the inconsistency of manual ultrasonic inspections and the variation in reliability (despite operators being qualified to the same level). It is widely accepted that automating ultrasonic inspections can improve reliability by:

- Automating scanning and improving confidence that full coverage is achieved;
- Collecting and processing data so that a permanent fingerprint is obtained in a format that is easier to interpret than manual A-Scan waveforms and which is available for review by a wider audience.

The radiograph generated during a radiographic inspection provides a permanent fingerprint and in this respect may be seen as having an advantage over manual UT. Therefore, a semi-automated inspection has been performed with the Mitsui Babcock SMARRT-Scan to illustrate typical ultrasonic fingerprint data.

The SMARRT-Scan system (see Annex A5) is a fully integrated inspection system comprising multi-channel flaw detector (8 channels), semi-automated (i.e. manually propelled) scanner, notebook PC and pumped couplant. The system is optimised for rapid and reliable detection and categorisation of service-induced defects in pipework welds.

5.3.2 Scope of Inspection

Testpiece TPF8 was selected on the basis of suitability for the SMARRT-Scan system (i.e. a pipe weld containing mainly planar defects in the throughwall direction).

The standard SMARRT-Scan set up focuses on the inner third of the weld but for the purposes of this project the set up was modified to cover the whole weld volume. The main objectives of the system are speed (single pass scanning if possible) and reliability (through appropriate technique selection and qualification). In this case the testpiece was scanned in a single circumferential pass. Detailed through wall sizing is possible (the scanner incorporates two axes and can perform B-scanning) but was not considered necessary for the purposes of this part of the project.

Two standard 70° shear wave and two specialised 70° compression wave techniques were deployed. The mode conversion properties of the compression wave techniques assist with the interpretation and characterisation of throughwall planar defects, which is especially useful given the limited amount of information generated by single pass scanning. These techniques have been qualified and used extensively on other applications.

It is vital that the system is set up carefully (and qualified where possible) and this can take some time. However, once the system is established, the scanning time is only a few minutes/weld which enables significantly shorter inspections than either manual UT or radiography.

Further details of the set up are provided in the report presented as Annex A5.

5.3.3 Results

Ten of the eleven intended defects were clearly detected by the system. Defect 6 was not detected (in common with the manual UT and RT inspections). This is not surprising since it is a small lack of inter-run fusion defect (intended dimensions 2mm height x 5mm long).

Analysis of the defect signals indicates good correlation (within the tolerances generally accepted for UT) with the intended defect locations and lengths.

A further three indications were recorded (and subsequently confirmed by manual UT). These are considered to be due to small, unintentional defects. (No scan data is presented for these indications).

The scan data files and a summary of the results are provided in the report presented in Annex A5. For clarity, individual C- and D-Scan images are provided for each defect (rather than a single scan file).

Note the flaw detector was calibrated for pulse-echo detection and consequently any mode conversion (e.g. self-tandem) signals, which are recorded along the main compression beam, require interpretation and re-plotting by a skilled operator. It is fair to say that, as with all automated ultrasonic inspection systems, there remains scope for human error at this and other stages of the inspection. Although semi- or fully automated ultrasonic inspection is considered to improve reliability (for the reasons outlined above), it is not foolproof.

These results could be used to help sentence the weld or retained in electronic or paper format as a fingerprint for comparison with future in-service inspection results. Performing precise repetitive automated inspection is straightforward providing the same equipment and set up is applied.

6. HUMAN FACTOR

The satisfactory outcome of a radiographic or ultrasonic inspection relies on the operators applying the procedure correctly hence the personnel must have suitable training, experience and qualification (e.g., PCN level 2).

Within reference [3] an experimental investigation into the human factor aspects of radiographic inspections by TWI is referenced. The results of five interpreters were analysed to look for any person-to-person variability in performance. The main conclusions were that there was little variation in the detected performance of the radiographers for the defects investigated and no significant variation was detected due to tiredness, boredom or becoming familiar. Flaw characterisation was generally accurate but in some cases large, highly misorientated flaws were misinterpreted as surface flaws.

Factors such as tiredness, boredom or familiarisation of the interpreter with the task, and the variability in performance from person-to-person also influence the inspection results of ultrasonic inspection as demonstrated by various studies including the recent PANI projects.

7. COST

Although it is recognised that HSE's main concerns are the health and safety implications of replacing radiography by ultrasonics, it is useful to consider the cost implications since these will also be considered by any organisation when deciding which method to use (when there is a choice).

Table 20 provides an indication of comparative costs. Note that it is only intended to provide an overview: actual costs will vary depending on details of the weld, inspection procedure, equipment used and organisation performing the inspection.

	Cost of equipment to purchase	Typical cost to provide service (per day)
Manual Pulse-Echo	< £5,000	£200-£500
Automated Pulse-Echo	£20,000 - £50,000 £50,001 - £100,000	£500 - £1000 £1000 - £2000
TOFD	£20,000 - £50,000	(£500 - £1000) £1000 - £2000
X-ray Radiography	£15,000 - £25,000	£160-£200
γ - ray Radiography	£5,000 – £20,000	£160-£200
Note: When two prices range is given = more than one equipment available.		

Table 20: Inspection cost (indicative only)

8. GUIDELINES

The following guidelines are intended to help identify when ultrasonics may be a suitable alternative to radiography for weld inspection. They are based on the reviews and practical trials carried out as part of this project, together with a general understanding of the capabilities and limitations of the two methods. Note that this project has concentrated on pulse-echo techniques, and the guidelines reflect this. Guidelines on the extent to which e.g. TOFD can be used to replace radiography are outside the scope of this project.

The guidance provided is based mainly on the extent to which ultrasonics can provide the same overall level of confidence in structural integrity of a joint as would be achieved by radiography. Clearly, the final choice (where there is flexibility to choose) will depend on consideration of an appropriate balance between:

- health and safety aspects associated with structural integrity (implications of missing defects during inspection)
- health and safety aspects associated with radiography
- costs and inspection time

Although this balance needs to be agreed on a case by case basis between the relevant parties, the guidelines below together with the overview of costs provided in Section 7 will hopefully provide a useful input to this decision.

1. Radiography and ultrasonics have different capabilities and limitations. Ultrasonics generally has a better capability for the detection of planar defects (e.g. cracks, lack of sidewall fusion etc.) whereas radiography generally has a better capability for volumetric defects (slag, porosity etc.)

2. Since planar defects are generally of greater concern than volumetric defects, ultrasonics can play a greater role in assuring structural integrity then radiography. Ultrasonics can also measure defect throughwall dimension, which is generally more important than defect length.

3. If ultrasonics is to be performed instead of radiography, this should only be done after proper consideration of the possible types, locations and orientations of defects of concern, so that appropriate ultrasonic techniques can be defined.

4. Inspection performance depends on both inherent capability of the method used, and its reliability in practice. Both radiography and ultrasonics can be adversely affected by human reliability (both during acquisition of data and during analysis). Available evidence suggests that radiography is less sensitive to human reliability factors than ultrasonics. The production of a permanent radiographic image of the weld which can be independently examined is also an advantage compared to manual ultrasonics (using conventional equipment). It is therefore important that any perceived advantage of ultrasonics in terms of capability, is not compromised by poor reliability during practical application. Reference [25] provides guidance on achieving reliable ultrasonic inspection.

5. Even though Codes and Standards may only reference ultrasonic inspection down to a specified minimum thickness of weld, satisfactory ultrasonic inspection capability may be achievable for significantly smaller thicknesses provided appropriate techniques are selected. For the specific geometries, defects and

techniques studied in this project, ultrasonics detected all planar defects, and most volumetric defects, in welds down to 4mm thick.

6. An undressed weld cap can have a greater influence on ultrasonics than radiography, mainly due to the restriction it presents to scanning. If ultrasonics is to be performed instead of radiography on an undressed weld, it is very important that satisfactory ultrasonic inspection can be performed from both sides of the weld. Dressing the weld cap will improve ultrasonic inspection capability.

7. The results of this project have demonstrated that for the ultrasonic inspection of thin (< 12mm) section welds, inspection from both sides using a 70º beam can be highly effective.

8. Both ultrasonic inspection capability and reliability will increase the greater the number of beam angles applied in each direction. The importance will increase with increasing weld thickess.

9. If ultrasonics is to be used instead of radiography and there is a concern about the reduced capability to detect porosity, inclusion of a probe with frequency above 2MHz is recommended.

10. If ultrasonics is to be used instead of ultrasonics and a high level of assurance is required that the inspection will achieve its objectives, then inspection qualification is recommended (see e.g. reference [25]). Since ultrasonic capability depends on a variety of defect parameters such as dimension, location, orientation and shape, it is recommended that qualification should be more comprehensive than the minimum required by ASME code case 2235.4. Semi-automated or fully automated inspection can provide significant improvements in reliability compared to manual ultrasonics.

11. Radiographic acceptance criteria are based on what can be detected on a radiograph. If ultrasonics is to be applied instead of radiography, it is important to recognise that different acceptance criteria are likely to be required. The inability of ultrasonics to detect and sentence defects according to radiographic criteria should not be considered a weakness of ultrasonics, any more than the inability of radiography to detect and sentence defects according to ultrasonic criteria. In many cases the defects which radiography detects but ultrasonics cannot detect (or sentence) are not of structural concern although they can provide useful quality control information on the welding process. However many of the defects which ultrasonics detects but radiography cannot detect (or sentence) are of structural concern.

9. CONCLUSIONS

This project covered the assessment of the extent to which ultrasonic inspection could replace radiography for weld inspection.

Radiographic and ultrasonic methods are the most commonly used inspection methods for volumetric inspection of welds. These two NDT methods have advantages and disadvantages as far as flaw detection, identification and sizing are concerned. Radiography is particularly suitable for detection and identification of volumetric defects such as cavities, solid inclusions, and incomplete penetration where a gap exists. Ultrasonic flaw detection is very suitable for the detection and sizing of planar defects such as cracks, lack of fusion and tight incomplete penetration in ferritic steel.

As a part of the project, a literature survey was carried out and the different code requirements (including ASME and BS EN standards) were reviewed and summarised. In particular, Code Case 2235-4 which covers the use of ultrasonic examination in lieu of radiography under the ASME code was reviewed.

The practical study carried out for this project showed that, even when optimised UT methods are used (note that the project has concentrated on pulse-echo techniques), some defects such as slag and porosity can still be difficult to detect and may therefore not be reported. The UT inspection techniques were capable of detecting all the critical defects (such as cracks) used for the study unlike RT which in several instances did not report some of those defects.

The study did not cover defect sizing as radiography does not measure throughwall dimensions. Therefore, the defect dimensions refered to in the study were intended dimensions. The discussion and conclusions would be unlikely to change significantly even if accurate defect dimensions were known.

Guidelines on the extent to which ultrasonic testing can replace radiography for weld inspection have been provided.

The choice as to whether radiographic or ultrasonic testing should be used to carry out an inspection should be based on consideration of the most suitable method for the particular application (including geometry, access, restriction) and material, together with economic and health and safety considerations. The choice should be agreed between the appropriate parties.

When UT inspection is selected, it should be performed using a detailed written procedure. In some cases its capability should be proven using a capability statement and/or modelling, and/or actual practical demonstration. Reliability can be increased by applying semi-automated or fully automated ultrasonic inspection.

There may be instances where it may be necessary to employ both methods on the same weld to complement the results from either method.

10. REFERENCES

[1] G A Georgiou and C R A Schneider, ‘Radiography of thin-section welds’, Insight Vol 45 No2, February 2003.

[2] A.B.Wooldridge, R.K. Chapman, G.S. Woodcock, I.J. Munns, G.A. Georgiou, ‘Demonstrating the capability of radiography for detection of large planar defects in thick-section welds’, NDTnet 1998 April, Vol.3 No4.

[3] G S Woodcock (2001), ‘Capability statement for the standard BEGL and BNFL Magnox radiography procedures, E/REP/NDT/0001/GEN/01, Issue 000, May 2001.

[4] BEGL Standard NDT Procedures – Radiographic Inspection of Welds, EPD/GEN/NDTS/P/16, Issue 6, July 1999.

[5] BNFL Magnox Company Standard – M/CS/TCED/705 Issue 3.

[6] BS EN 1435: 1997 – Non Destructive Examination of Welds – Radiographic Examination of Welded Joints.

[7] C G Pollitt, ‘Radiographic sensitivity’, British Journal of NDT, Sept. 1962, pp71-80.

[8] G. Georgiou, ‘Adopting European Ultrasonic Standards for Fabrications: Implications For Manufacturers and End Users’, TWI 5657/10/95.

[9] O.Fofli, B.Hansen, S.Sandberg & T.Astrom ‘A Comparison of Radiographic and Ultrasonic NDE’ 90/75948.

[10] 2001 ASME Boiler & Pressure Vessel Code Section V.
Nondestructive examination.

[11] 2001 ASME Boiler & Pressure Vessel Code Section III.
Division 1 – Subsection NB: Class 1 components.

[12] 2001 ASME Boiler & Pressure Vessel Code Section III.
Division 1 – Subsection NC: Class 2 components.

[13] 2001 ASME Boiler & Pressure Vessel Code Section III.
Division 1 – Subsection ND: Class 3 components.

[14] 2001 ASME Boiler & Pressure Vessel Code Section III
Division 1 – Subsection NF: Supports.

[15] 2001 ASME Boiler & Pressure Vessel Code Section III
Division 1 – Appendices: appendix VI.

[16] 2001 ASME Boiler & Pressure Vessel Code Section XI.
Division 1 – Article IWB 3000 ‘Acceptance Standars’ and
Appendix 1: ‘Ultrasonic Examinations’.

[17] Cases of ASME Boiler and Pressure Vessel Code – Code Case 2235-4: ‘Use of Ultrasonic Examination in Lieu of Radiography, Section I and Section VIII, Divisions 1 and 2.

[18] BS EN 13480-5:2002 – Metallic industrual piping – Part 5; Inspection and testing.

[19] BS EN 1714:1998 – Non-destructive testing of welded joints – Ultrasonic testing of welded joints.

[20] BS 3923 Part 1 1986 - Ultrasonic examination of welds – Methods for manual examination of fusion welds in ferritic steels.

[21] BS EN 1712:1997 – Non-destructive testing of weld – Ultrasonic testing of welded joints – Acceptance levels.

[22] PD 5500:2003 – Specification for unfired fusion welded pressure vessels – Section 5.6.

[23] BS EN 12062:1998 – Non-destructive examination of welds – General rules for metallic materials.

[24] B. A. McGrath , 'Programme for the Assessment of NDT in Industry', HSE report on CD-ROM, Dec 1999.

[25] HSE Best Practice for the Procurement and Conduct of Non-Destructive Testing. Part 1: Manual Ultrasonic Testing. www.hse.gov.uk/dst/ndt1.pdf.

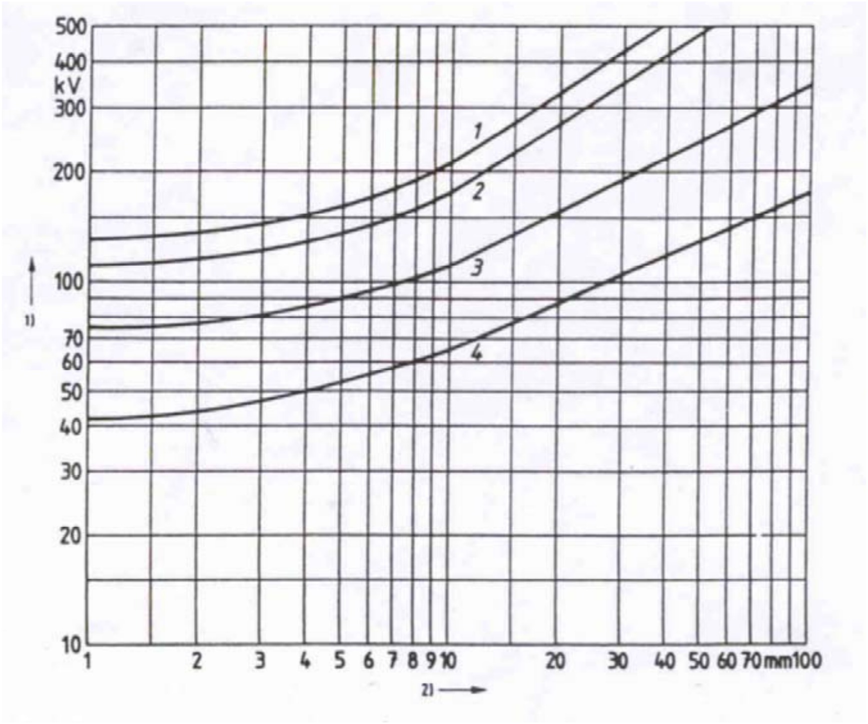
ANNEXES

ANNEX A1: CODE REQUIREMENT – RADIOGRAPHY

A1.1. REVIEW OF BS EN 1435:1997

European standards are conceptually very strict in guidelines for radiographic procedures. Two testing classes with different parameters and testing quality are described in the general rules. Different minimum requirements are defined to produce a certain spatial resolution and/or contrast. To ensure sufficient spatial resolution (the distance between details which can just be separated in a radiographic image), the minimum film-to-object distance is calculated from the focal spot size or source size and the object thickness. Different wire IQI values must be achieved, depending on the penetrated thickness and required image quality class, a minimum optical film density is also required.

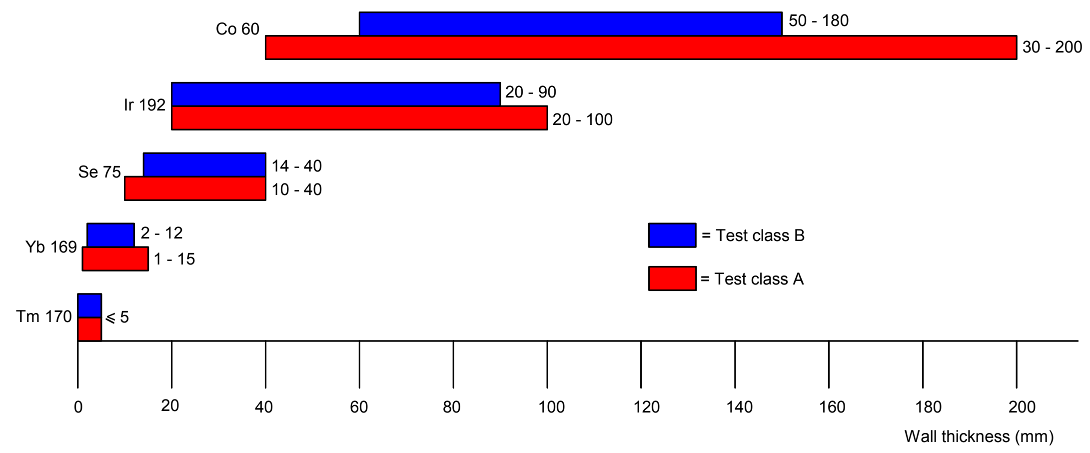
Additionally, maximum X-ray voltages (Figure A1.1) and minimum film system class qualities are defined depending on the wall thickness and testing class. The usage of gamma sources is permitted for certain wall thickness ranges, depending on the testing class (Figure A1.2).



1 Copper/nikel and alloys
2 Steel
3 Tittanium and alloys
4 Aluminium and alloys

1) X-ray voltage
2) Penetrated thickness w

Figure A1.1 – Maximum X-ray voltage for X-ray devices up to 500kV as a function of penetrated thickness and material



Notes : -

1. If permitted by specification, the value for Ir 192 may be further reduced to 10 mmand for Se 75 to 5 mm.
2. On thin steel specimans, gamma rays from Se 75, Ir 192 and Co 60 will not produce radiographs having as good a defect detection sensitivity as X-rays used with appropriate technique parameters.

Figure A1.2 – Penetrated thickness range for gamma ray sources corresponding to EN 1435 – for steel, copper and nickel-based alloys

The intention of this standard is that it shall guarantee a minimum image quality by applying minimum requirements for the radiographic technique being employed, that is:

- **Contrast** – Optical density, IQI values, maximum X-ray energies and choice of radiation source.
- **Film system classes and metal screens** – Definition of film classes is dependant on radiation source and penetrated thickness.
- **Geometric Unsharpness** – Minimum source-to-object distance, filters and collimators.

The standard does not specify acceptance levels for any indications found nor does it specify any guidelines for radiographic interpretation or characterisation of indications.

The radiographic techniques are subdivided into two classes:

- Class A: basic techniques.
- Class B: improved techniques

In class A, if planar imperfections have to be detected, the minimum source-to-object distance shall be the same as class B.

The standard states that class B techniques will be used when class A might be insufficiently sensitive.

In critical technical applications of crack sensitive materials, more sensitive radiographic techniques than B shall be used. No guidelines are given as to how better than class B is to be achieved.

A1.1.1 Review scope

The European Standard BS EN 1435:1997 specifies fundamental techniques of radiography based on generally recognized practice and fundamental theory of the subject. The standard applies to the radiographic testing of fusion welded joints in metallic materials. With specific reference made to copper/nickel and alloys, titanium and alloys, aluminium and alloys, and steel.

It applies to the joints of plate or pipes and complies with EN 444 (Non-destructive testing – General principles for radiographic examination of metallic materials by X- and gamma-rays).

A1.1.2 Normative references

Reference is made to: -

a) EN 444 – Non-destructive testing – general principles for the radiographic examination of metallic materials using X- and gamma rays.

b) EN 462 series – Non-destructive testing – image quality of radiographs

c) EN 473 – Qualification and certification of non-destructive personnel – General principles.

d) EN 584 series – Non-destructive testing – Industrial radiographic film.

e) EN 25580 – Non-destructive testing – Industrial radiographic illuminators.

See Figure A1.3 for scheme of standards for measurement of equipment properties, clasification, application of techniques and minimum requirements.

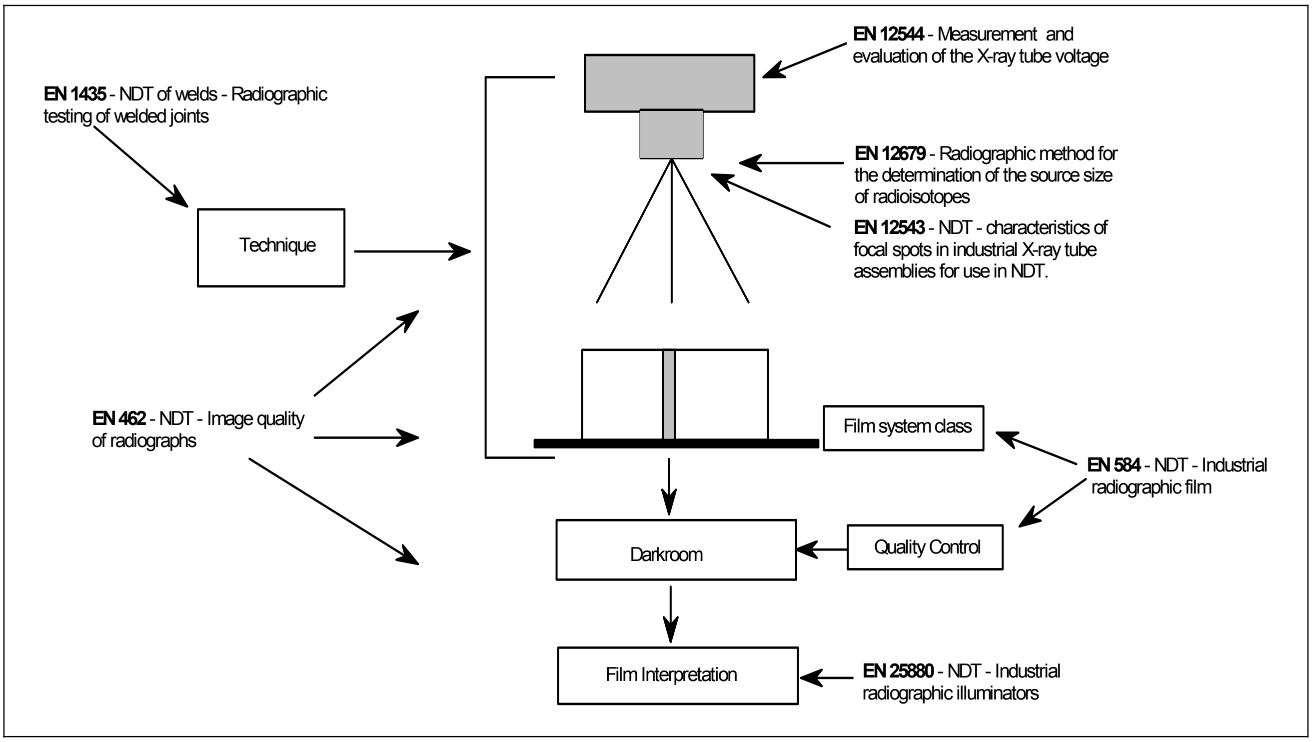


Figure A1.3 – Schematic of standards

A1.2. ACCEPTANCE LEVELS

A number of standards exist giving tables of acceptance standards for imperfections found in welds for the purpose of this document the following standards giving acceptance levels have been reviewed: -

1. BS EN 12517:1998 – Non-destructive testing of welds – Radiographic testing of welded joints – Acceptance levels.
2. BS EN 13480-5: 2002 – Metallic industrial piping – Part 5:Inspection and testing

The acceptance levels for indications are shown in Table A1.1. The imperfection types are those listed in EN 25817 – Arc welded joints in steel – Guidance on quality levels for imperfections.

No.	Type of imperfections in accordance with EN 26520	Acceptance level 3[1]	Acceptance level 2[1]	Acceptance level 1[1]
1	Cracks (100)	Not permitted	Not permitted	Not permitted
2	Crater cracks (104)	Permitted one per each 40 mm of the weld	Not permitted	Not permitted
3	Porosity and gas pores (2011, 2013, 2014 and 2017)	$l \le \min(0.5\,s;\ 5\text{ mm})$ $\Sigma\, l \le s$ for $L = \min(12\,s;\ 150\text{mm})$	$l \le \min(0.4\,s;\ 4\text{ mm})$ $\Sigma\, l \le s$ for $L = \min(12\,s;\ 150\text{mm})$	$l \le \min(0.3\,s;\ 3\text{ mm})$ $\Sigma\, l \le s$ for $L = \min(12\,s;\ 150\text{mm})$
4	Wormholes (2016)	$l \le \min(0.5\,s;\ 4\text{ mm})$ $\Sigma\, l \le s$ for $L = \min(12\,s;\ 150\text{mm})$	$l \le \min(0.4\,s;\ 3\text{ mm})$ $\Sigma\, l \le s$ for $L = \min(12\,s;\ 150\text{mm})$	$l \le \min(0.3\,s;\ 2\text{ mm})$ $\Sigma\, l \le s$ for $L = \min(12\,s;\ 150\text{mm})$
5	Solid and metallic inclusions (300) and elongated cavities (2015)	$l \le 2\,s$ and $\Sigma\, l \le L/10$ for $L = \min(12\,s;\ 150\text{mm})$	$l \le s$ and $\Sigma\, l \le L/10$ for $L = \min(12\,s;\ 150\text{mm})$	$l \le \max(0.3\,s;\ 6\text{ mm})$ $\Sigma\, l \le s$ for $L = \min(12\,s;\ 150\text{mm})$
6	Copper inclusions (3042)	Not permitted	Not permitted	Not permitted
7	Lack of fusion (401)	Permitted, but only intermittently and not breaking the surface $l \le 25$ mm and $\Sigma l \le 25$ mm for $L = \min(12\,s;\ 150\text{mm})$	Not permitted	Not permitted
8	Lack of penetration (402)			
9[2]	Undercut (501)			
10[2]	Excessive penetration (504)			
11[2]	Local protrusion (5041)	Permitted	Occasional local excess permitted provided the transition is smooth	
12[2]	Stray flash and spattert (601), (602)	Acceptance of stray flash depends on type of parent metal and likelihood of cracking		
		Acceptance of spatter depends on type of parent metal		

[1] Acceptance levels 3 and 2 may be specified with prefix X, which denotes that all indications over 25 mm are unacceptable.

[2] Surface imperfections: the acceptance levels are those defined for visual testing. These imperfections are normally accepted or rejected for visual testing.

Table A1.1 – Acceptance levels for indications in butt welds

A1.2.1 Quality Levels – EN 25817:1992

Level symbol	Quality level
D	Moderate
C	Intermediate
B	Stringent

Table A1.2 – Quality levels for weld imperfections

A1.2.2 Radiographic Technique – EN 12517:1998

Depending on the weld quality level, radiographic techniques A or B in accordance with EN 1435 is used as shown in Table A1.3.

Quality levels in accordace with EN 25817 or EN 30042	Testing techniques and levels in accordance with EN 1435	Acceptance levels in accordance with EN 12517
B	B	1
C	B(1)	2
D	A	3
(1) However, the maximum area for a single exposure shall correspond to the requirements of class A of EN 1435		

Table A1.3 – Radiographic testing

A1.2.3 Acceptance Levels – EN 12517:1998

The symbols used in Table A2.3 are the following:

l is the length of imperfection, in millimetres;

s is the minimal butt weld thickness, in millimetres;

L is the tested length of the welded joint, in millimetres;

h is the height of imperfection, in millimetres;

b is the width of weld reinforcement, in millimetres.

EN 12517:1998 gives a table which shows the generally accepted methods of testing welds for internal imperfections. This table is partly reproduced below as Table A1.4.

Materials and type of joint	Thickness in mm (t = Nominal thickness of parent plate to be welded)		
	$t \leq 8$	$8 < t \leq 40$	$t > 40$
Ferritic butt-joints	RT or (UT)	RT or UT	UT or (RT)
Austenitic butt-joints	RT	RT or (UT)	RT or (UT)

Table A1.4 – generally accepted methods for detection of internal imperfections for butt-joints with full penetration

A1.2.4 Guide to the limitations of radiography – EN 12517:1998

NOTE: - The numbers in parenthesis conform to those used in EN 26520

A1.2.4.1 Volumetric imperfections in butt welds

- Porosities and gas pores (2011, 2013, 2015, and 2017).
- Wormholes and elongated cavities (2016 and 2015)
- Solid and metallic inclusions (300)
- Copper inclusions (3042)

The above imperfections listed in Table A1.4 will be readily detected using radiographic technique A or B of EN 1435 as shown in Table A1.3.

A1.2.4.2 Cracks in butt welds

- Crater cracks (104)
- Cracks (100)

The detectability of cracks by radiography depends on the crack height, the ramification (presence of branching parts), opening width, orientation of the X-ray beam and radiographic technique parameters.

Reliable detection of all cracks is therefore limited. The use of radiographic technique B or better, as specified in EN 1435, will provide better crack detectability than radiographic technique A.

A1.2.4.3 Planar imperfections in butt welds

- Lack of fusion (401)
- Lack of penetration (402)

The detection of lack of fusion and lack of penetration depends on characteristics of imperfections and radiographic technique parameters.

Lack of side wall fusion will probably not be detected (unless it is associated with another flaw such as slag) unless it is favourably orientated to the X-ray beam.

A1.2.5 BS EN 13480 Metallic Industrial Piping – Part 5: Inspection and Testing (Supersedes BS 806 : 1993)

A1.2.5.1 Surface condition and preparation for non-destructive testing:

RT: surface dressing is required where ripples or weld surface irregularities will interfere with the interpretation of the radiographs.

A1.2.5.2 Application of NDT

For RT the method and acceptance criteria are specified as given in Table A1.5.

RT is to be performed in accordance with written NDT procedures, and, where appropriate, with NDT instructions.

NDT Technique (abbreviation)	**Method**	**Acceptance Criteria**
Radiographic Testing (RT)	EN 1435:1997, class B [a b]	EN 12517:1998 Acceptance level 2 and additional requirements of Table 6

[a] However, the maximum area for single exposure shall correspond to the requirements of EN 1435:1997, class A.

[b] Class A for material group 1.1, 1.2, 8.1 (refer to table 8.2-1 of EN 13480-5:2002) when piping class is I or II.

Table A1.5 – NDT techniques, method, acceptance criteria

A1.2.5.3 Acceptance Criteria

The acceptance criteria are the same as EN 12517 (Level 2) with additional requirements for acceptance criteria for internal imperfections detected by RT as given in Table A1.6.

Identification of internal imperfection			Maximum permitted imperfection			
EN ISO 6520-1:1998 Reference number	Designation	EN 25817:1992 Reference number	Piping class in accordance with EN 13480-1:2002, Table 4.1-1			Additional requirements [a]
			III	II	I	
			EN 25817:1992, quality level			
1001-1064	Cracks (all)	1	Not permitted			
2011-2016	Gas cavity (all)	3-5	B	B	C	For No 20121, the distance between two pores shall always be greater than twice the diameter of the bigger one, and not less than 4 mm (to ensure that there is no chance of having a lack of fusion) For No 2014 same as for uniformly distributed pores For No 2015 and 2016 /= 0.3 *t*, maximum 5 mm, and *w* = 2 mm
2021-2024	Shrinkage cavity (all)	-	Not permitted			
3011-3014 3021-3024 303	Slag inclusions (all) Flux inclusions (all) Oxide inclusions	6	1.			1. *w* = 0.3 *t*, maximum 3 mm and depending of the application: 1 < *t* ≤ 25 mm In cases of several line at slag inclusions with a distance between 2 of them less than twice the longest of them, the total length is to be considered as a defect.
3042	Metallic inclusions (copper)	7	Not permitted			
3041 and 3043	Metallic inclusions (all others)	-	2.			2. Same as for gas cavities No 2011 – 2012 – 2013
4011-4013	Lack of fusion (all)	8	Not permitted			
402	Lack of penetration	9	Not permitted			If a full penetration weld is required
-	Multiple imperfections in any cross section	26	B	B	B	

[a] Symbols according to EN 25817:1992, *w* = maximum size of cavity

Table A1.6: Additional requirements for acceptance criteria for internal imperfections detected by RT

A1.3. REVIEW OF THE ASME BOILER AND PRESSURE VESSEL CODE.

The International Boiler and Pressure Vessel Code establishes rules of safety governing the design, fabrication, and inspection of boilers and pressure vessels, and nuclear power plant components during construction.

The objectives of the rules are to provide a margin for deterioration in service. Advancements in design and material and the evidence of experience are constantly being added by Addenda.

Section V contains requirements and methods for nondestructive examination that are referenced and required by other code Sections.

It also includes manufacturer's examination responsibilities, duties of authorized inspectors and requirements for qualification of personnel, inspection and examination.

Examination methods are intended to detect surface and internal discontinuities in materials, welds, and fabricated parts and components, a glossary of related terms is also included.

A detailed breakdown of each section, division and subsection is given Table A1.7.

A1.3.1 QUALITY OF RADIOGRAPHS – ASME 2001 Section V

This section states that radiography will be consistant in sensitivity and resolution only if the effect of all details of techniques, such as geometry, film, filtration, viewing etc; is obtained and maintained.

To obtain quality radiographs, it is necessary to consider as a minimum the following list of items,

1. Radiation source (X-ray or gamma).
2. Voltage selection (X-ray).
3. Source size (X-ray or gamma).
4. Ways and means to eliminate scattered radiation.
5. Film system class.
6. Source-to-film distance.
7. Image quality indicators (IQIs).
8. Screens and filters.
9. Geometry of part or component configuration.
10. Identification and location markers.
11. Radiographic quality level.

A1.3.2 ASME Acceptance standard

Section III of the ASME code is divided into 7 subsections covering different classes and types of components as shown in Table A1.7, for the purpose of this review the following subsections where considered and their acceptance standards for radiography reviewed: -

ASME Section III Subsection NB – Class 1 components
ASME Section III Subsection ND – Class 3 components

I. Power Boilers
II. Materials
Part A-Ferrous Material Specifications
Part B NonFerrous Material Specifications
Part C -Specifications for Welding Rods, Electrodes, and Filler Metals
Part D -Properties (Customary)
Part D -Properties (Metric)
III. Rules for Construction of Nuclear Facility Components
Subsection NCA - General Requirements for Divisions 1 and 2
DIVISION 1
Subsection NB - Class 1 Components
Subsection NC - Class 2 Components
Subsection ND - Class 3 Components
Subsection NE - Class MC Components
Subsection NF - Supports
Subsection NG - Core Support Structures
Subsection NH - Class 1 Components in Elevated Temperature Service
Appendices
DIVISION 2
Code for Concrete Containments
DIVISION 3
Containments for Transportation and Storage
IV. Heating Boilers
V. Nondestructive Examination
VI. Recommended Rules for the Care and Operation of Heating Boilers
VII. Recommended Guidelines for the Care of Power Boilers
VIII. Pressure Vessels
DIVISION 1
DIVISION 2 - Alternative Rules
DIVISION 3 - Alternative Rules for Construction of High Pressure Vessels
IX. Welding and Brazing Qualifications
X. Fiber-Reinforced Plastic Pressure Vessels
XI. Rules for Inservice Inspection of Nuclear Power Plant Components
XII. Rules for Construction and Continued Service of Transport Tanks
Code Cases: Boilers and Pressure Vessels
Code Cases: Nuclear Components

Table A1.7: Sections of the ASME boiler and pressure vessel code.

Category A	Category A comprises longitudinal weleded joints within the main shell, communication chambers, transition in diameter, or nozzles; any welded joint withi n a sphere, within a formed or flat head, or within the side plates of a flat sided vessel; and circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.
Category B	Category B comprises circumferential welded joints within the main shell, communicating chambers, nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; and circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.
Category C	Category C comprises welded joints connecting flanges, Van Stone laps, tube-sheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers any welded joint connecting one side plate to another side plate of a flat sided vessel.
Category D	Category D comprises welded joints connecting communicating chambers or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat sided vessels, and those joints connecting chambers. For nozzles at the small end of a transition in diameter, see category B.

Note: the term category defines the location of a joint in a vessel, but not the type of joint.

Table A1.8: Welded joint category

Both subsections consider the following indication and impose parameters for being unacceptable: -

a) Any indication characterised as a crack or zone of incomplete fusion or penetration – unacceptable.

b) Any other elongated indication, which has a length greater than the imposed parameters are unacceptable.

c) Internal root weld conditions are acceptable when the density change as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in b) above.

d) Any group of aligned indications having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication.

e) Rounded indications shown in excess of the imposed parameters are unacceptable.

Subsection ND states the following additional acceptance standards: -

f) When a Category B or C (see Table A1.8) butt weld, partially radiographed as required by the Code, is acceptable in accordance with a) through to e) above, the entire weld length represented by this partial radiograph is acceptable.

g) When a Category B or C butt weld, partially radiographed as required by the Code, has been examined and any radiograph dicloses welding which does not comply with the minimum quality requiremnts a) through e) above, one additional section at least 150mm long, for each radiograph disclosing such defective welding, but a minimum total of two, shall be radiographically examined in the same weld unit at other locations. The locations of these additional radiographs shall be acceptable to the Inspector.

   i. If the additional sections examined show welding which meets the minimum quality reuirements of a) through e) above, the entire weld unit represented by the total number of radiographs is acceptable. The weld repaired areas shall be radiographically examined.

   ii. If any of the additional sections examined shows welding which does not comply with the minimum quality requirements of a) through e) above, the entire unit of weld represented shall be rejected. The entire rejected weld represented shall be rewelded, or the entire unit of weld represented shall be completely radiographed and any part of the weld not meeting the requiremnts of a) through e) above shall be repaired and reexamined radiographically. The rewelded joint shall be partially radiographed as required by the Code or the weld repaired areas shall be radiographically reexamined.

A1.3.3 General guide to imperfections and NDE methods

Table A1.9 is based on table A-110 in Article 1 of Section V of the ASME Code. The table gives general guidelines as to the types of imperfections and the NDE methods that are capable of detecting them.

	Surface [Note (1)]		Sub-Surface [Note (2)]		Volumetric [Note (3)]				
	VT	PT	MT	ET	RT	UTA	UTS	AE	UTT
Service-Induced Imperfections									
Abrasive Wear (Localized)	A	B	B		A	B	B		B
Baffle Wear (Heat Exchangers)	**A**			B					
Corrosion-Assisted Fatique Cracks	C	B	A		C	A		A	
Corrosion - Crevice	A								C
- General / Uniform				C	B		B		A
- Pitting	**A**	**A**	C		A	C	C	B	C
- Selective	**A**	**A**	C						C
Creep (Primary) [Note (4)]									
Erosion	A				A	C	B		B
Fatique Cracks	C	**A**	**A**	B	B	A		A	
Fretting (Heat Exchanger Tubing)	B			B					B
Hot Cracking		B	B		B	C		B	
Hydrogen-Induced Cracking		B	B		C	B		B	
Intergranular Stress-Corrosion Cracks						C			
Stress-Corrosion Cracks (Transgranular)	C	B	A	C	B	B		B	
Welding Imperfections									
Burn Through	A				A	B			C
Cracks	C	**A**	**A**	B	B	A	C	A	
Excessive/Inadaquate Reinforcement	A				A	B	C		C
Inclusions (Slag/Tungsten)			B	B	**A**	B	C	C	
Incomplete Fusion	B		B	B	B	A	B	B	
Incomplete Penetration	B	**A**	**A**	B	A	**A**	B	B	
Misalignment	A				**A**	B			
Overlap	B	**A**	**A**	C		C			
Porosity	**A**	**A**	C		A	B	C	C	
Root Concavity	A				**A**	B	C	C	C
Undercut	A	B	B	C	**A**	B	C	C	
Product Form Imperfections									
Bursts (Forgings)	C	A	A	B	B	B	B	A	
Cold Shuts (Castings)	C	**A**	**A**	C	A	B	B	C	
Cracks (All Product Forms)	C	**A**	**A**	B	B	B	C	A	
Hot Tear (Castings)	C	**A**	**A**	B	B	B	C	C	
Inclusions (All Product Forms)			B	B	A	B	C	C	
Laminations (Plate, Pipe)	C	B	B			C	A	C	A
Laps (Forgings)	C	**A**	**A**	C	B		C	C	
Porosity (Castings)	**A**	**A**	C		A	C	C	C	
Seams (Bar, Pipe)	C	**A**	**A**	C	C	B	B	C	

Legend: AE – Acoustic Emission ET – Electromagnetic (Eddy Current) MT – Magnetic Particle
RT – Radiography PT – Liquid Penetrant UTA – Ultrasonic Angle Beam
UTS – uultrasonic Straight Beam UTT – Ultrasonic Thickness Measurement VT – Visual
A – All or most standard techniques will detect this imperfection under most conditions.
B – One or more standard technique(s) will detect this imperfection under certain conditions
C – Special techniques, conditions, and/or personnel qualifications are required to detect this imperfection

GENERAL NOTE: Table lists imperfections and NDE methods that are capable of detecting them. IT must be kept in mind that this table is very general in nature. Many factors influence the detectability of imperfections. This table assumes that only qualified personnel are performing nondestructive examinations and good conditions exist to perfom examination (good access, surface conditions, cleanliness, etc.).

NOTES:

(1) Methods capable of detecting imperfections that are open to the surface only.
(2) Methods capable of detecting imperfections that are either open to the surface or slightly subsurface.
(3) Methods capable of detecting imperfections that may be located anywhere within the examined volume.
(4) Various NDE methods are capable of detecting tertiary (3^{rd} stage) creep and some, particularly using special techniques, are capable of detecting secondary (2^{nd} stage) creep. There are various descriptions/definitions for the stages of creep and a particular description/definition will not be applicable to all materials and product forms.

Table A1.9: Imperfection against type of NDE method as referenced by ASME boiler and pressure code

A1.4. SUMMARY

Radiography as a method of non-destructive examination for detecting imperfections in welds requires the user to consider a number of parameters, see Figure A1.3 and Figure A1.4 below, which need to be considered in order to achieve an acceptable level of detection.

BS EN 1345 gives guidelines in order to achieve a minimum radiographic quality but optimization of the parameters will achieve the best radiographic sensitivity.

A number of standards exist that set out acceptance standards and quality levels for radiographs, in all but the least stringent, both cracks and lack of fusion defects are unacceptable, the type of defects most difficult to detect by radiography.

The limitations on radiography for detecting cracks and lack of fusion type defects is well documented in the technical literature and is highlighted in EN 12517:1998.

Theorectical models such as the simple Pollitt theory are available to calculate the probability of detection of particular flaw types under specified radiographic conditions; none of the standards reviewed referenced the use of such models.

Radiographic sensitivity is generally based around the measurement of the thinnest wire visible on the radiograph over the material thickness and expressed as a percentage: -

$$\text{Flaw sensitivity} = \frac{\text{Diameter of thinnest wire}}{\text{Material thickness}} \quad \text{X } 100\%$$

From this it can be deducted that flaw detectability deteriorates as the thickness of steel radiographed increases. Some acceptance standards therefore base imperfection acceptance as a ratio of the component thickness.

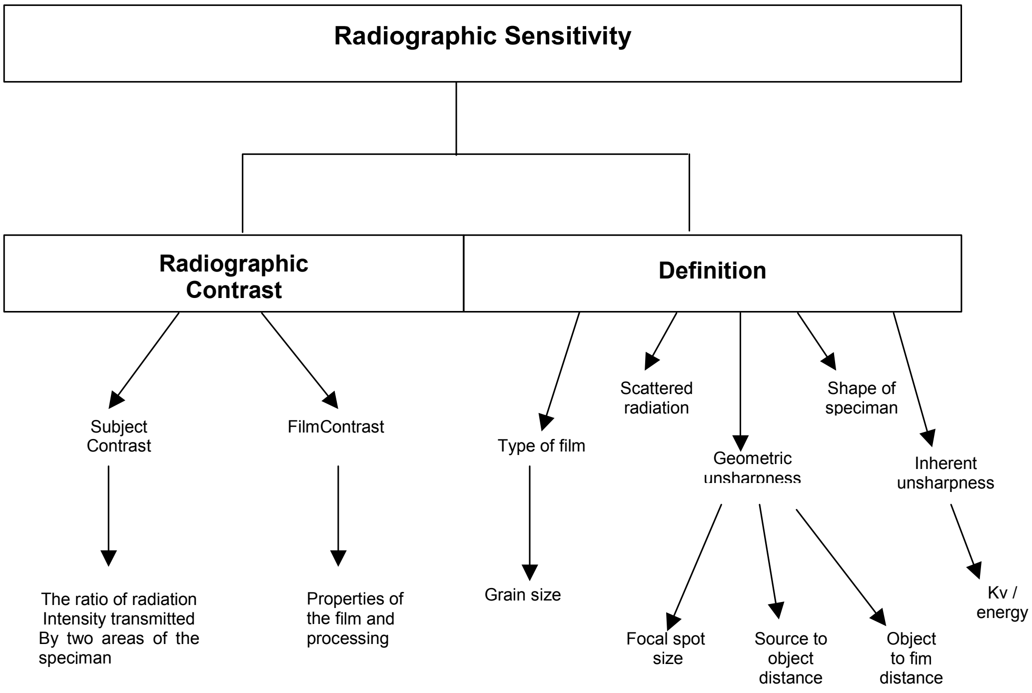


Figure A1.4 – Radiographic sensitivity parameters.

ANNEX A2: TESTSAMPLES

	Sample ID	Type	Cap & Root	Dimens.			Defect							RT Type
				Dia. OD	T	L	Total No.	Non Planar	Planar	Intended Tilt	Intended Height	Length	Comments	
1.	P8241	Pipe	∗	50	4	300	2	0	2	-	NI	15	Root crack	X-ray
										-	NI	14	Root crack	
2.	P8242	Pipe	∗	50	4	300	5	3	2	-	NI	3	Tung. Inclusion	X-ray
										-	NI	12	Porosity	
										-	NI	15	LoRF	
										-	NI	3	Root pores	
										-	NI	10	Toe crack	
3.	P8239	Pipe	∗	50	5	300	3	2	1	-	NI	20	Root crack	X-ray
										-	NI	12	Porosity	
										-	NI	3	2xtung. inclusions	
4.	P8240	Pipe	∗	50	5	300	3	1	2	-	NI	12	LoRP	X-ray
										-	NI	15	LoRF	
										-	NI	20	Porosity	
5.	P8243	Pipe	∗	75	6	300	5	2	3	-	NI	18	Toe crack	X-ray
										-	NI	20	Toe crack	
										-	NI	10	LoRF	
										-	NI	2	Pore	
										-	NI	9	Slag	
6.	P8244	Pipe	∗	75	6	300	5	4	1	-	NI	10	Porosity	X-ray
										-	NI	12	Root crack	
										-	NI	5	Pore	
										-	NI	10	Tun. Inclusion	
										-	NI	10	Slag	
7.	TPF6	Pipe	√	457	12.5	300	10	3	7	15	3	18	Crack	X-ray & γ-ray
										37.5	2	10	LoSWF	
										20	3	14	Crack	
										-	3	20	Porosity	
										37.5	3	18	LoSWF	
										37.5	3	17	Toe crack	
										37.5	3	12	LoSWF	
										0	3	18	Root crack	
										-	1-2	12	Slag	
										-	2	14	Root undercut	
8.	P8301	Pipe	√	304	35	300	11	3	8	-	4^{∇}	27	LoRF	X-ray
										0	7^{∇}	28	Root crack	
										0	6.5^{∇}	20	Toe crack	
										-	NI	19	Slag	
										0	8^{∇}	29	Centre line crack	
										-	3^{∇}	17	LoRF	
										-	NI	25	Porosity	
										30	3^{∇}	38	LoSWF	
										-	NI	3	Tung. Inclusion	
										30	3^{∇}	28	LoSWF	
										0	8^{∇}	25	Root crack	
9.	TPF8	Pipe	√	457	35	300	11	2	9	60	4	22	LoSWF- lower	γ-ray
										15	4	22	LoSWF - upper	
										0	2	21	LoRP	
										15	4	16	HAZ Crack	
										0	2	18	Root crack	
										70	2	5	Lack of inter-run fusion	
										0	6	20	Tight planar smooth root defect	
										15	4	18	Rough planar	
										10	4	15	Rough planar	
										5	4	14	Rough planar	
										0	4	18	Root crack	

√ = Cap & root present
∗ = Cap & root undressed and cap dressed
$^{\nabla}$ = Defect height provided by manual UT

Note:
- All the dimensions are in millimetres except the tilt which is in degrees.
- NI = No Information Provided
- Defect height not checked for this study.
- RT carried out on undressed samples unless specified.

Table A2.1: Summary of the samples used for the study – Pipes.

	Sample ID	Type	Cap & Root	Dimens.			Defect							RT Type
				Dia. OD	T	L	Total No.	Non Planar	Planar	Intended Tilt	Intended Height	Length	Comments	
10.	2557-001	Plate	∗	NA	4	300	4	1	3	10 0 35 0	2 2 3 3	10 10 15 15	Rough planar Rough planar LoSWF Rough planar	X-ray$^{\Diamond}$ & γ-ray
11.	2557-002	Plate	∗	NA	8	300	4	0	4	35 10 40 40	3 3 5 4	15 15 15 15	LoSWF Rough planar LoSWF Rough planar HAZ	X-ray$^{\Diamond}$ & γ-ray
12.	2557-003	Plate	∗	NA	10	300	4	0	4	10 0 0 0	4 5 3 3	20 20 10 15	Rough planar Rough planar LoF Rough planar	X-ray$^{\Diamond}$ & γ-ray
13.	2557-004	Plate	∗	NA	12	300	4	0	4	35 10 40 0	3 4 3 4	15 20 15 15	LoSWF, OD surf. Break Rough planar LoSWF LoRF	X-ray$^{\Diamond}$ & γ-ray
14.	TPF7	Plate	√	NA	15	300	4	1	3	30 37.5 - 15	3 4 1-2 4	15 12 10 20	Toe crack LoSWF Slag Rough planar	X-ray & γ-ray
15.	PL8227	Plate	√	NA	25	300	5	2	3	NI NI NI - -	NI NI NI NI NI	18 20 25 15 27	LoRF Toe crack Root crack Slag Porosity	X-ray
16.	PL8228	Plate	√	NA	25	300	7	2	5	- NI NI NI NI NI -	NI NI NI NI NI NI NI	2 22 15 30 20 13 4	Tung. Inclusion Root crack Root crack LoRF LoF LoRF Tung. inclusion	X-ray

√ = Cap & root present
∗ = Cap & root undressed and cap dressed
$^{\Diamond}$ = X-rays carried out on dressed sample

Note:
- All the dimensions are in millimetres except the tilt which is in degrees.
- NI = No Information Provided
- Defect height not checked for this study.
- RT carried out on undressed samples unless specified

Table A2.2: Summary of the samples used for the study - Plates.

ANNEX A3: SI/08/88 - TESTSAMPLE MANUFACTURER’S SIZING AND REPORTING CRITERIA

SENSITIVITY SETTINGS, SIZING TECHNIQUES AND FLAW REPORTING CRITERIA FOR STANDARD FLAWED SPECIMENS

A) RECOMMENDED SENSITIVITY SETTINGS, SIZING TECHNIQUES AND DEFECT REPORTING CRITERIA FOR ULTRASONIC INSPECTION

This procedure is recommended for setting sensitivity levels, defect sizing and determination of reporting criteria to ensure an accurate and standardised report format.

A1: Sensitivity Levels for Shear Wave and Compression Probes:-

i) Reference Sensitivity the Distance Amplitude Curve from 1.5mm (0.6 in) diameter side drilled hole should be set with the highest response at Full Screen Height.

A2. Search Sensitivity reference + 6 to 8dB.

A3. Sizing defect using Shear wave probes:

i) Defect length 6dB drop off using centre of beam and for through wall depth 6dB drop off using centre of beam, and/or 20dB drop off.

A4. Sizing defects using Compression wave probes:

i) Defect length 6dB drop off using centre of beam.

Note: It is advisable that a suitable plotting aid be used.

B) DEFECT REPORTING CRITERIA FOR ULTRASONIC INSPECTION

All defect indications over 10mm (0.3 in) long and with an amplitude greater than 12dB shall be reported.

REPORTING CRITERIA FOR DISCIPLINES OTHER THAN ULTRASONIC INSPECTION

Defect Category	**Defect Type**	**Reporting Criteria**
Planar Defects	Cracks or lamillar tears	All cracks to be reported regardless of length
	Lack of root fusion Lack of sidewall fusion Lack of inter-run fusion Lack of root penetration	Reportable if length is greater than 10mm (0.3 in)
Cavities	Isolated or individual pores	Reportable if diameter is greater than 3mm (0.125 in)
	Group porosity	Reportable if length or diameter is greater than 10mm (0.3 in)
Solid inclusions	Isolated or individual inclusions	Reportable if length is greater than 10mm (0.3 in)
	Linear and parallel to weld axis	Reportable if greater than 10mm (0.3 in) in length

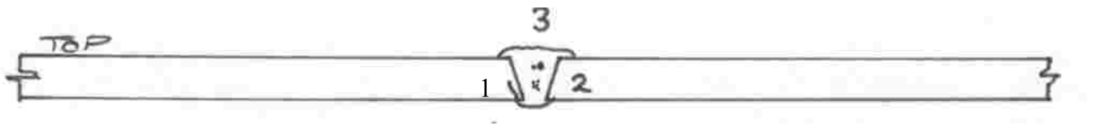
ANNEX A4: INSPECTION RESULTS

A4.1. SMALL BORES TESTSAMPLES

A4.1.1 Testsample P8239

Sample Description

Radiographic sample, 50mm OD, 5mm thick. See radiographic results for details. Weld preparation angle: 30°.



Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Root Crack	20	15
2	Porosity	12	60
3	2xTungsten	3	95
Comments	Results for the sample with and without the weld cap removed.		

Table A4.1: X-rays results

Ultrasonic Results

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	200	38	12	20
2	36	53	6	62
3	36	53	3	100

Table A4.2: Results using 70° contoured single 4MHz probe - weld cap undressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from 0 (mm)
1	159	43	17	15
2	80	49	14	57
3	Not Found*			
Comments	* Remark: The volume of the tungsten inclusions may have been reduced during the weld dressing process.			

Table A4.3: Results using 70° contoured single 4MHz probe – weld cap dressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	178	55	12	20
2	25	72	6	62
3	63	64	3	100

Table A4.4: Results using 70° contoured twin 4MHz probe- weld cap undressed

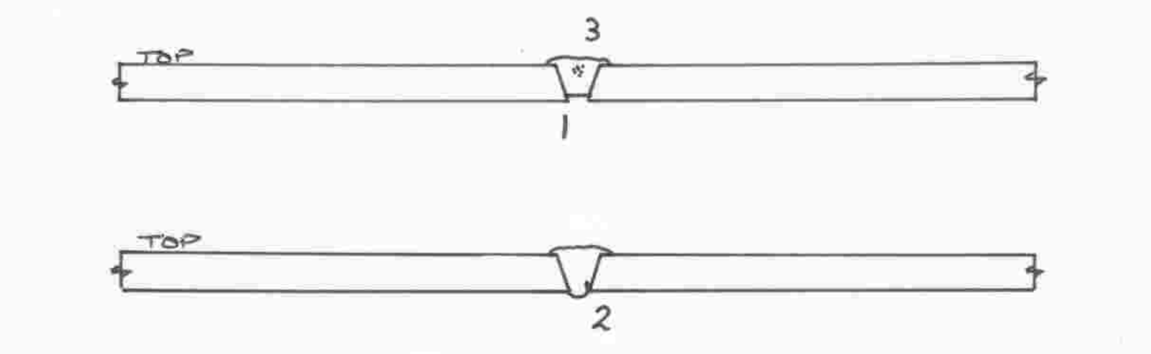
Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	159	59	18	15
2	70	66	13	58
3	Not Found*			
Comments	* Remark: The volume of the tungsten inclusions may have been reduced during the weld dressing process.			

Table A4.5: Results using 70° contoured twin 4MHz probe- weld cap dressed

A4.1.2 Testsample P8240

Sample Description

Radiographic sample, 50mm OD, 5mm thick. See radiographic results for details. Weld preparation angle: 30°.



Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Incomplete root penetration	12	43
2	Lack of root fusion	15	85
3	Porosity	20	125
Comments	Flaw 2 not clearly visible on radiograph. Results for the sample with and without the weld cap removed.		

Table A4.6: X-rays results

Ultrasonic Results

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum(mm)
1	200	38	9	48
2	159	40	12	85
3	Not found			

Table A4.7: Results using 70° contoured single 4MHz probe - weld cap undressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	159	43	12	43
2	125	45	15	85
3	28	58	17	126

Table A4.8: Results using 70° contoured single 4MHz probe - weld cap dressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	141	57	9	48
2	141	57	12	85
3	Not found			

Table A4.9: Results using 70° contoured twin 4MHz probe- weld cap undressed

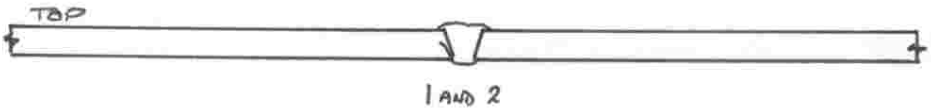
Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	316	53	11	42
2	200	57	15	85
3	50	69	19	124

Table A4. 10: Results using 70° contoured twin 4MHz probe- weld cap dressed

A4.1.3 Testsample P8241

Sample Description

Radiographic sample, 50mm OD, 4mm thick. See radiographic results for details. Weld preparation angle: 30°.



Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from 0 (mm)
1	Root Crack	15	15
2	Root Crack	14	110
Comments	Results for the sample with and without the weld cap removed		

Table A4.11: X-rays results

Ultrasonic Results

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	200	38	15	15
2	125	58	15	101

Table A4.12: Results using 70° contoured single 4MHz probe - weld cap undressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	100	47	15	15
2	100	47	13	115

Table A4.13: Results using 70° contoured single 4MHz probe - weld cap dressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	10	4	15	15
2	125	58	15	101

Table A4.14: Results using 70° contoured twin 4MHz probe - weld cap undressed

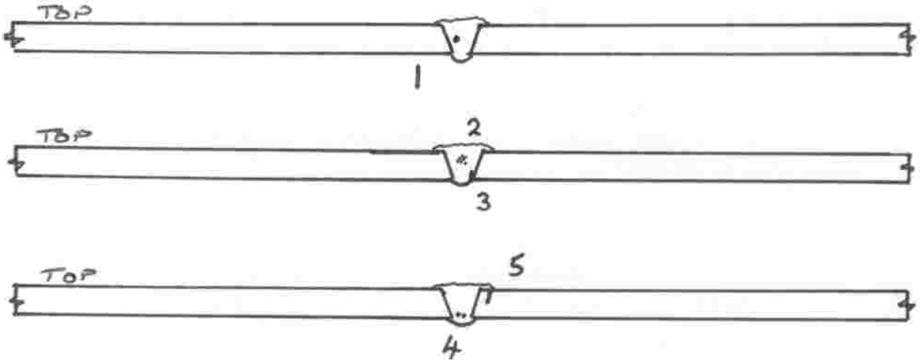
Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	282	54	14	15
2	224	56	13	115

Table A4.15: Results using 70° contoured twin 4MHz probe - weld cap dressed

A4.1.4Testsample P8242

Sample Description

Radiographic sample, 50mm OD, 4mm thick. See radiographic results for details. Weld preparation angle: 30°.



Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Tungsten inclusion	3	25
2	Porosity	12	53
3	Lack of root fusion	15	87
4	Root pores	3	110
5	Toe crack	10	125
Comments	Flaw 4 is a none manufacturing defect. The results provided in this table are from radiographs taken of the sample with and without the weld cap removed.		

Table A4.16: X-rays results

Ultrasonic Results

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	Not found			
2	50	50	8	58
3	200	38	15	88
4	Not found			
5	125	42	8	130

Table A4.17: Results using 70° contoured single 4MHz probe - weld cap undressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	Not found			
2	25	59	11	52
3	200	41	15	89
4	16	63	spot	110
5	32	57	10	125

Table A4.18: Results using 70° contoured single 4MHz probe - weld cap dressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	Not found			
2	45	67	8	58
3	200	54	15	88
4	Not found			
5	141	57	8	130

Table A4.19: Results using 70° contoured twin 4MHz probe - weld cap undressed

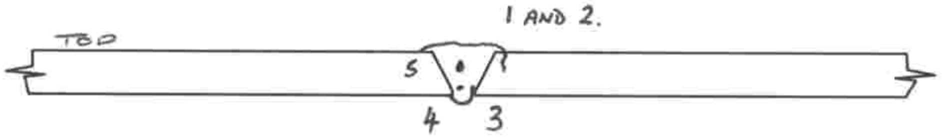
Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	Not found			
2	80	65	11	52
3	200	57	15	89
4	45	70	Spot	110
5	159	59	10	125

Table A4.20: Results using 70° contoured twin 4MHz probe - weld cap dressed

A4.1.5Testsample P8243

Sample Description

Radiographic sample, 75mm OD, 6mm thick. See radiographic results for details. Weld preparation angle: 30°.



Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Toe crack	18	45
2	Toe crack	20	97
3	Lack of root fusion	10	150
4	Pore	2	165
5	Slag	9	180
Comments	Flaw 4 is a none manufacturing defect Results for the sample with and without the weld cap removed		

Table A4.21: X-rays results

Ultrasonic Results

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	200	38	18	47
2	178	39	14	100
3	282	35	14	148
4	Not found			
5	141	41	5	181

Table A4.22: Results using 70° contoured single 4MHz probe - weld cap undressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	200	43	18	49
2	224	42	20	97
3	316	39	10	148
4	10	69	Spot	166
5	56	54	9	180

Table A4.23: Results using 70° contoured single 4MHz probe - weld cap dressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	224	53	18	47
2	224	53	14	100
3	282	51	14	148
4	Not found			
5	200	54	5	181

Table A4.24: Results using 70° contoured twin 4MHz probe - weld cap undressed

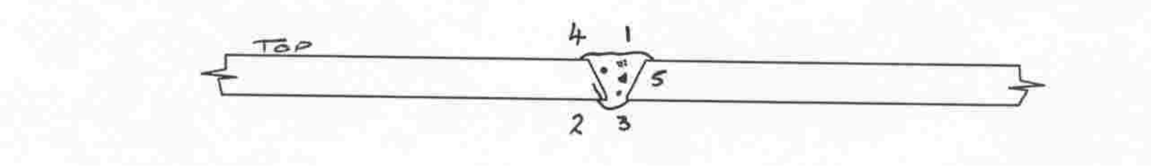
Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	282	49	18	49
2	355	47	20	97
3	251	50	10	148
4	13	76	Spot	166
5	100	58	8	180

Table A4.25: Results using 70° contoured twin 4MHz probe - weld cap dressed

A4.1.6Testsample P8244

Sample Description

Radiographic sample, 75mm OD, 6mm thick. See radiographic results for details. Weld preparation angle: 30°.



Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Porosity	10	5
2	Root crack	12	95
3	Pore	5	110
4	Tungsten inclusion	10	160
5	Slag	10	190
Comments	Results for the sample with and without the weld cap removed.		

Table A4.26: X-rays results

Ultrasonic Results

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	159	40	6	5
2	200	38	11	98
3	Not found			
4	Not found			
5	200	38	7	193

Table A4.27: Results using 70° contoured single 4MHz probe – weld cap undressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	40	57	10	5
2	141	46	12	95
3	Not found			
4	Not found			
5	80	51	10	192

Table A4.28: Results using 70° contoured single 4MHz probe – weld cap dressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	159	56	6	5
2	251	52	11	98
3	Not found			
4	Not found			
5	159	56	7	193

Table A4.29: Results using 70° contoured twin 4MHz probe – weld cap undressed

Defect No	% DAC	Signal dB Gain to DAC	Flaw Length (mm)	Distance from datum (mm)
1	45	65	9	7
2	224	51	12	95
3	Not found			
4	Not found			
5	125	56	10	193

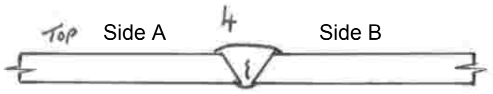
Table A4.30: Results using 70° contoured twin 4MHz probe – weld cap dressed

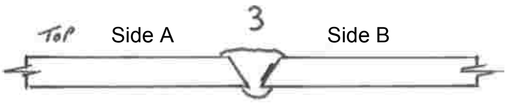
A4.2. PLATES

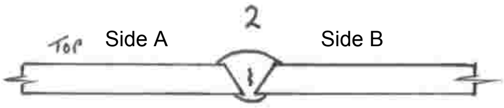
A4.2.1 Testsample 2557-001

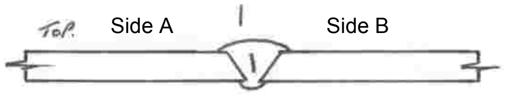
Sample Description

Flaw No	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Centre line crack	10	230
2	Centre line crack	10	170
3	Lack of sidewall fusion	15	112
4	Centre line crack	15	49
Comments	Sample thickness = 4mm Weld preparation angle: 30°.		









Radiographic Results

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Linear porosity	10	240
2	Linear porosity	20	160
3	Not found		
4	Not found		
Comments	Pore at 110mm, T/Inclusion at 250mm and 270mm.		

Table A4.31: X-rays results – weld cap undressed (inspector 1).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Linear pores + LoF	10	230
2	Linear pores + LoF	10	170
3	Not found*		
4	Not found		
Comments	Missed root edge/misalignmemt from 0 to 40mm. Pore at 40mm. *Pores (various) at 105mm to 120mm. Shadow at 105mm to 120mm & suspect area at 290mm for 10mm.		

Table A4.32: X-rays results – weld cap undressed (level 3 inspector 2)

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Crack + linear pores	15	230
2	Crack + pores	12	170
3	Crack + linear pores	15	110
4	Crack	15	50
Comments	Small crack at the end of the plate from 290mm to 300mm		

Table A4.33: X-rays results – weld cap dressed (level 3 inspector 2)

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Not found		
3	Not found		
4	Not found		
Comments	No comments		

Table A4.34: γ-rays results – weld cap undressed (inspector 1).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Not found		
3	Not found		
4	Not found		
Comments	Pore at 110mm, 170mm & 240mm. Shadows: from 160mm to 170mm and from 240mm to 250mm		

Table A4.35: γ-rays results – weld cap undressed (level 3 inspector 2)

Ultrasonic Results

Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	90	49	90	49	16	49
2	178	43	125	46	13	114
3	159	44	Not found		9	170
4	100	48	141	45	10	230

Table A4.36: Results using 70° single 4MHz probe - weld cap undressed

Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	112	47	100	48	16	49
2	141	45	200	42	13	114
3	141	45	200	42	9	170
4	112	47	100	48	10	230

Table A4.37:Results using 70° single 4MHz probe - weld cap dressed

Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	90	56	70	58	10	230
2	100	55	100	55	7	172
3	125	53	Not found		10	117
4	80	57	90	56	14	50

Table A4.38: Results using 70° twin 4MHz probe - weld cap undressed

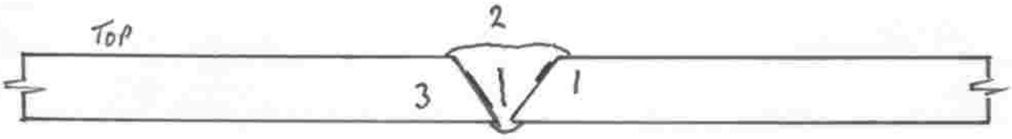
Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	178	52	112	56	10	230
2	200	51	112	56	7	172
3	251	49	200	51	10	117
4	316	47	159	53	14	50

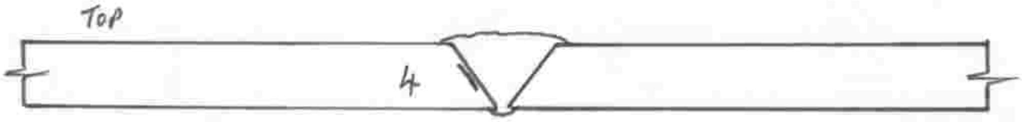
Table A4.39:Results using 70° twin 4MHz probe - weld cap dressed

A4.2.2Testsample 2557-002

Sample Description

Flaw No	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Lack of sidewall fusion	13	233
2	Centre line crack	15	173
3	Lack of sidewall fusion	15	113
4	Sidewall crack	15	52
Comments	Sample thickness = 8mm Weld preparation angle: 30°. Sample as welded		





Radiographic Results

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Linear porosity	20	170
3	Not found		
4	Suspected LoSWF	20	40
Comments	Wormhole with tail at 50mm and a pore at 120mm.		

Table A4.40: X-rays results – weld cap undressed (inspector 1)

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Missed cap edge	18	225
2	Pores and crack	22	170
3	Not found*		
4	LoSWF	15	40
Comments	Pores at 0mm, 65mm, 200mm, 210mm, 220mm. *Pores (various sizes) from 110mm for 10mm. Wormhole at 45mm. Incomplete penetration at 290mm for 4mm.		

Table A4.41: X-rays results – weld cap undressed (level 3 inspector 2)

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Missed cap edge/ LoSWF	18	225
2	Pores & crack	22	170
3	Not found*		
4	LoSWF	15	40
Comments	Pores at 0mm, from 200mm to 220mm. *Pores (various sizes) from 110mm for 10mm. Wormhole at 45mm. Shadow from 280mm to 290mm.		

Table A4.42: X-rays results – weld cap dressed (level 3 inspector 2)

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Not found		
3	Not found		
4	Not found		
Comments	Wormhole with tail at 50mm and a pore at 120mm.		

Table A4.43: γ-rays results – weld cap undressed (inspector 1)

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Linear pores & slag line	10	170
3	Not found		
4	Root undercut	15	40
Comments	Pore at 120mm. Wormhole at 45mm. Incomplete penetration at 290mm for 3mm.		

Table A4.44: γ-rays results – weld cap undressed (level 3 inspector 2)

Ultrasonic Results

Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	125	46	70	51	13	232
2	178	43	178	43	15	173
3	159	44	80	50	15	113
4	112	47	56	53	10	57

Table A4.45: Results using 70° single 4MHz probe - weld cap undressed

Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	159	44	178	43	13	232
2	141	45	224	41	15	173
3	200	42	400	36	15	113
4	125	46	80	50	14	51

Table A4.46: Results using 70° single 4MHz probe - weld cap dressed

Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	50	61	36	64	12	233
2	141	52	100	55	15	173
3	159	51	70	58	14	113
4	125	53	45	62	11	57

Table A4.47: Results using 70° twin 4MHz probe - weld cap undressed

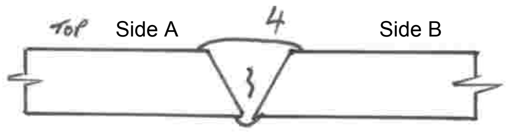
Defect No	1.5mm SDH				Flaw Length (mm)	Distance from datum (mm)
	Inspection from side A		Inspection from side B			
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	159	51	178	50	13	232
2	141	52	178	50	15	171
3	159	51	316	45	14	112
4	125	53	112	54	12	53

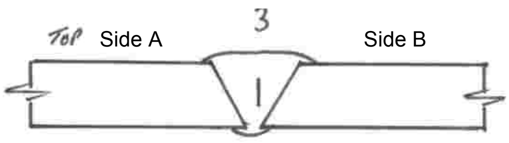
Table A4.48:Results using 70° twin 4MHz probe - weld cap dressed

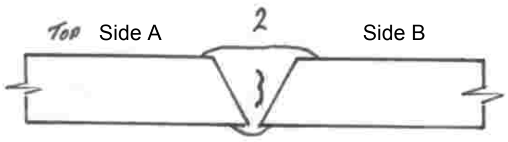
A4.2.3 Testsample 2557-003

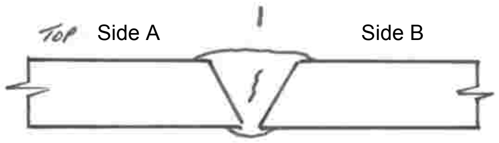
Sample Description

Flaw No	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Centre line crack	20	229
2	Centre line crack	20	170
3	Smooth crack	10	113
4	Centre line crack	15	50
Comments	Sample thickness = 10mm. Weld preparation angle: 30°. Sample as welded.		









Radiographic Results

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Linear porosity	20	160
3	Not found		
4	Not found		
Comments	Pores detected at 20mm, 40mm and 250mm		

Table A4.49: X-rays results – weld cap undressed (inspector 1).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Pores associated with LoF	20	160
3	Not found		
4	Not found		
Comments	Group of pores at 20mm, 50mm, 100mm, 200mm and 290mm cluster from 120mm to 130mm and from 225mm to 240mm. Wormhole at 240mm for 5mm. Wormhole and pores at 270mm for 5mm.		

Table A4.50: X-rays results – weld cap undressed (level 3 inspector 2).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Slag/LoF	23	230
2	Pores associated with LoF	22	170
3	Not found		
4	Not found*		
Comments	Pore at 0mm (cluster), 20mm, 50mm & 220mm. *Shadow from 50mm to 65mm. Wormhole and pores at 270mm for 5mm.		

Table A4.51: X-rays results – weld cap dressed (level 3 inspector 2).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Not found		
3	Not found		
4	Not found		
Comments	Pores detected at 40mm, 160mm and 250mm		

Table A4.52: γ-rays results – weld cap undressed (inspector 1).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	LoF	20	230
2	Not found		
3	Not found		
4	Not found		
Comments	Pores at 40mm, 165mm & 200mm Wormhole at 180mm		

Table A4.53: γ-rays results – weld cap undressed (level 3 inspector 2).

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	100	24	-	-
2	90	25	80	26
3	-	-	-	-
4	100	24	100	24

Table A4.54: Results using 45° single 2MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	32	32	14	42
2	50	28	63	26
3	-	-	-	-
4	80	24	28	33

Table A4.55: Results using 45° single 4MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	36	55	50	52	19	229
2	141	43	80	48	18	170
3	32	56	32	56	10	114
4	125	44	36	55	14	52

Table A4.56: Results using 45° single 4MHz probe - weld cap undressed (Inspector 2)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	25	125	70	30
2	26	112	141	24
3	34	45	50	33
4	27	100	159	23

Table A4.57: Results using 60° single 2MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	70	30	56	32
2	90	28	70	30
3	28	38	25	39
4	56	32	80	29

Table A4.58: Results using 60° single 4MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	50	49	100	43	20	229
2	100	43	100	43	18	170
3	32	53	36	52	10	113
4	141	40	45	50	15	50

Table A4.59: Results using 60° single 4MHz probe - weld cap undressed (Inspector 2)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	200	20	63	30
2	141	23	112	25
3	80	28	90	27
4	100	26	141	23

Table A4.60: Results using 70° single 2MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	70	29	63	30
2	50	32	125	24
3	32	36	28	37
4	70	29	178	21

Table A4.61: Results using 70° single 4MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	141	45	159	44	20	229
2	100	48	90	49	20	170
3	125	46	90	49	10	113
4	282	39	125	46	15	51

Table A4.62: Results using 70° single 4MHz probe - weld cap undressed (Inspector 2)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	100	32	90	33
2	100	32	178	27
3	56	37	40	40
4	90	33	200	26

Table A4.63: Results using 70° twin 4MHz probe - weld cap undressed (Inspector 1)

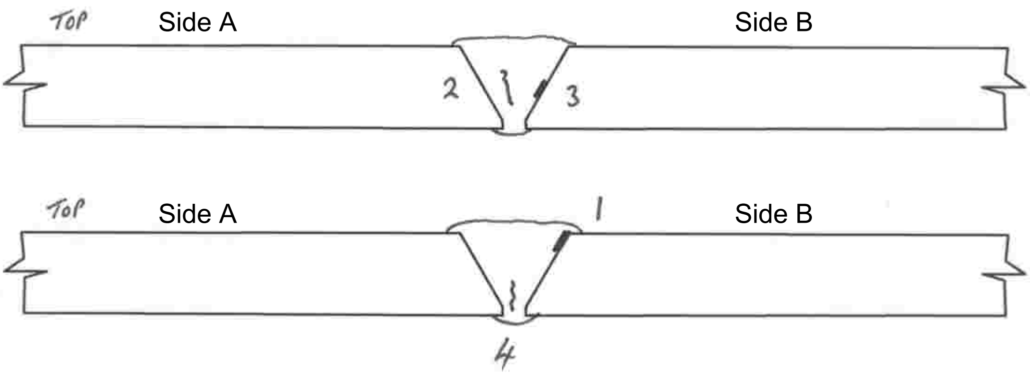
Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	282	48	282	48	20	229
2	400	45	282	48	20	170
3	178	52	178	52	10	113
4	562	42	501	43	15	51

Table A4.64: Results using 70° twin 4MHz probe - weld cap undressed (Inspector 2)

A4.2.4Testsample 2557-004

Sample Description

Flaw No	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Lack of sidewall fusion	16	233
2	Centre line crack	18	167
3	Lack of sidewall fusion	15	111
4	Centre line crack	17	50
Comments	Sample thickness = 12mm Weld preparation angle: 30°. Sample as welded		



Radiographic Results

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Lack of Fusion	30	160
3	Not found		
4	Not found		
Comments	Pores at 50mm, 100mm, 160mm and 170mm		

Table A4.65: X-rays results – weld cap undressed (inspector 1).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	LoF	25	165
3	Not found		
4	Crack	17	40
Comments	Pores at 0mm, 90mm, 110mm, 125mm, 175mm, 250mm and 285mm.		

Table A4.66: X-rays results – weld cap undressed (level 3 inspector 2).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	LoF	25	165
3	LoF	10	112
4	Not found		
Comments	Pores at 0mm, 90mm, 95mm, 110mm, 125mm, 175mm and 285mm.		

Table A4.67: X-rays results – weld cap dressed (level 3 inspector 2).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Lack of Fusion	30	160
3	Not found		
4	Not found		
Comments	Pore at 100mm		

Table A4.68: γ-rays results – weld cap undressed (inspector 1).

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Not found		
2	Not found*		
3	Not found		
4	Crack	15	40
Comments	Pore at 110mm. *Irregular root at 165mm for 20mm.		

Table A4.69: γ-rays results – weld cap undressed (level 3 inspector 2).

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	200	18	282	15
2	125	22	112	23
3	90	25	224	17
4	251	16	178	19

Table A4.70: Results using 45° single 2MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	159	18	224	15
2	80	24	80	24
3	40	30	90	23
4	200	16	80	24

Table A4.71: Results using 45° single 4MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	141	43	355	35	16	228
2	141	43	100	46	18	167
3	80	48	178	41	16	110
4	316	36	178	41	17	50

Table A4.72: Results using 45° single 4MHz probe - weld cap undressed (Inspector 2)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	141	24	178	22
2	125	25	125	25
3	45	34	355	16
4	112	26	224	20

Table A4.73: Results using 60° single 2MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	224	20	141	24
2	125	25	112	26
3	141	24	355	16
4	90	28	100	27

Table A4.74: Results using 60° single 4MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	224	36	141	40	16	228
2	112	42	125	41	15	169
3	125	41	355	32	15	110
4	80	45	125	41	17	50

Table A4.75: Results using 60° single 4MHz probe - weld cap undressed (Inspector 2)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	100	26	200	20
2	141	23	100	26
3	100	26	224	19
4	159	22	251	18

Table A4.76: Results using 70° single 2MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	112	25	80	28
2	178	21	125	24
3	224	19	282	17
4	282	17	251	18

Table A4.77: Results using 70° single 4MHz probe - weld cap undressed (Inspector 1)

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	90	49	50	54	18	228
2	159	44	159	44	18	167
3	100	48	251	40	15	110
4	400	36	400	36	16	50

Table A4.78: Results using 70° single 4MHz probe - weld cap undressed (Inspector 2)

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	100	32	80	34
2	224	25	159	28
3	355	18	355	21
4	251	24	316	22

Table A4.79: Results using 70° twin 4MHz probe - weld cap undressed (Inspector 1)

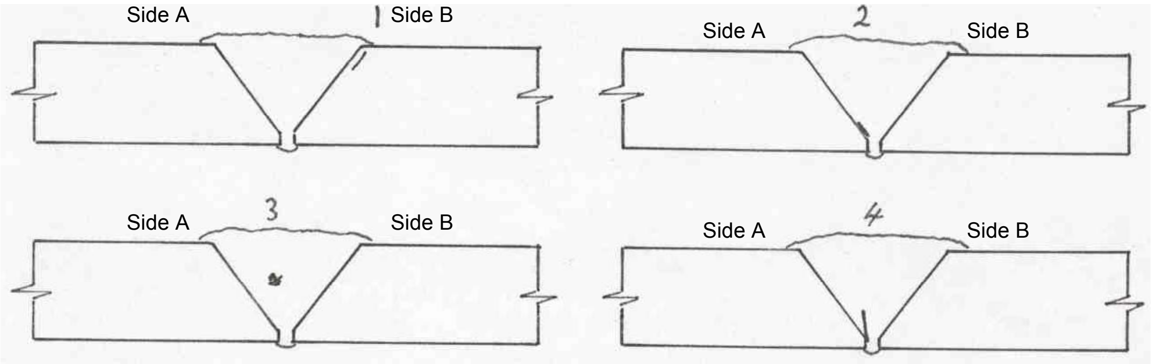
Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	100	57	50	63	18	228
2	178	52	178	52	18	167
3	159	54	400	45	14	110
4	355	46	631	41	18	52

Table A4.80: Results using 70° twin 4MHz probe - weld cap undressed (Inspector 2)

A4.2.5Testsample TPF7

Sample Description

Flaw No	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Toe crack	18	52
2	Lack of sidewall fusion	12	114
3	Slag	10	175
4	Crack	20	230
Comments	Sample thickness = 14mm. Weld preparation angle: 37.5°. Sample as welded		



Radiographic Results

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Crack at cap edge	15	50
2	Not found		
3	Cavity	10	170
4	Crack	10	240
Comments	Random porosity through out the weld. Transverse indication at 35 to 40mm (possibly due to porosity), Isolated pore at 60 and 120mm, cluster porosity at 150 and 240mm. Tungsten inclusion at 70mm.		

Table A4.81: X-rays results

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Crack at cap edge	15	50
2	Not found		
3	Cavity	10	170
4	Crack	10	240
Comments	Isolated pore at 60 and 120mm. Cluster porosity at 150 and 240mm. Tungsten inclusion at 70mm.		

Table A4.82: γ-rays results

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NF	NF	80	30	13	55
2	NF	NF	NF	NF	NF	NF
3	70	31	70	31	5	176
4	63	32	NF	NF	12	230

NF = Not found

Table A4.83: Results using 45° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NF	NF	100	36	17	54
2	NF	NF	NF	NF	NF	NF
3	80	38	20	50	8	175
4	NF	NF	NF	NF	NF	NF

NF = Not found

Table A4.84: Results using 45° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NF	NF	63	34	13	55
2	224	23	70	33	12	115
3	40	38	25	42	8	175
4	50	36	NF	NF	21	230

NF = Not found

Table A4.85: Results using 60° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NF	NF	63	42	13	55
2	50	32	63	42	13	115
3	63	42	56	43	9	176
4	56	43	25	50	21	229

NF = Not found

Table A4.86: Results using 60° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NF	NF	63	34	13	53
2	355	19	355	19	13	113
3	63	34	40	38	7	176
4	80	32	200	24	19	230

NF = Not found

Table A4.87: Results using 70° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NF	NF	50	40	13	55
2	112	33	141	31	14	112
3	50	40	50	40	7	178
4	36	43	70	37	19	230

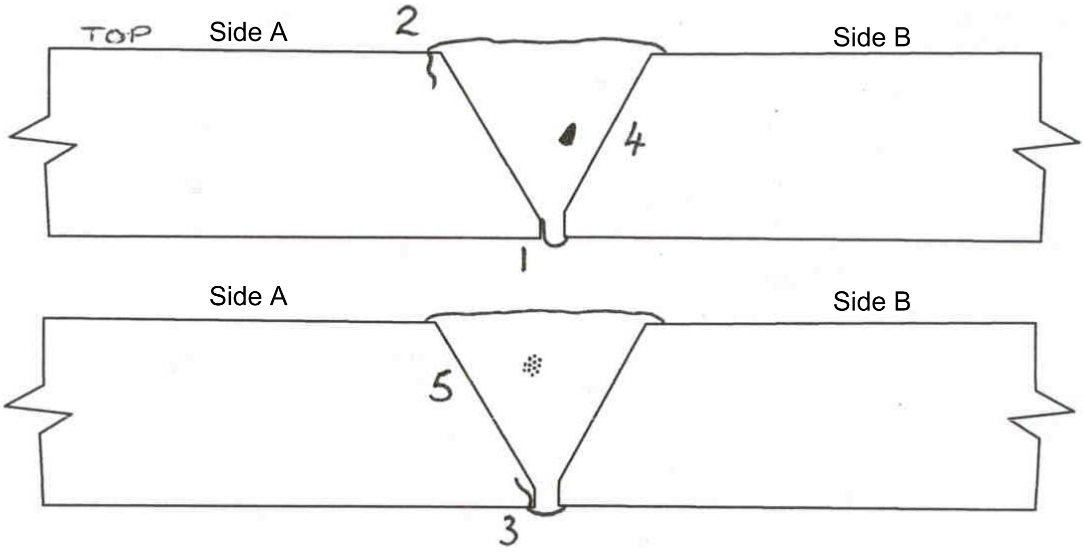
NF = Not found

Table A4.88: Results using 70° single 4MHz probe

A4.2.6Testsample PL8227

Sample Description

Radiographic sample, 25mm thick. See radiographic results for details.
Weld preparation angle: 30°.



Radiographic Results

Flaw No	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Lack of root fusion	18	15
2	Toe crack	20	32
3	Root crack	25	115
4	Slag	15	165
5	Porosity	27	230
Comments	Sample thickness = 25mm. Sample as welded		

Table A4.89: X-rays results

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	36	49	NF	NF
2	178	35	NF	NF
3	141	37	NF	NF
4	NF	NF	NF	NF
5	NF	NF	NF	NF

NF = Not found

Table A4.90: Results using 45° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	80	43	25	53
2	80	43	63	45
3	56	46	45	48
4	NF	NF	80	43
5	56	46	16	57

NF = Not found

Table A4.91: Results using 45° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	90	40	NF	NF
2	178	34	NF	NF
3	80	41	141	36
4	NF	NF	10	61
5	NF	NF	NF	NF

NF = Not found

Table A4.92: Results using 60° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	70	41	NF	NF
2	50	43	112	37
3	70	41	80	40
4	NF	NF	90	39
5	56	43	251	29

NF = Not found

Table A4.93: Results using 60° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	100	40	NF	NF
2	90	41	NF	NF
3	100	40	NF	NF
4	NF	NF	NF	NF
5	NF	NF	NF	NF

NF = Not found

Table A4.94: Results using 70° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	63	43	NF	NF
2	36	48	NF	NF
3	159	35	100	39
4	NF	NF	10	61
5	NF	NF	11	58

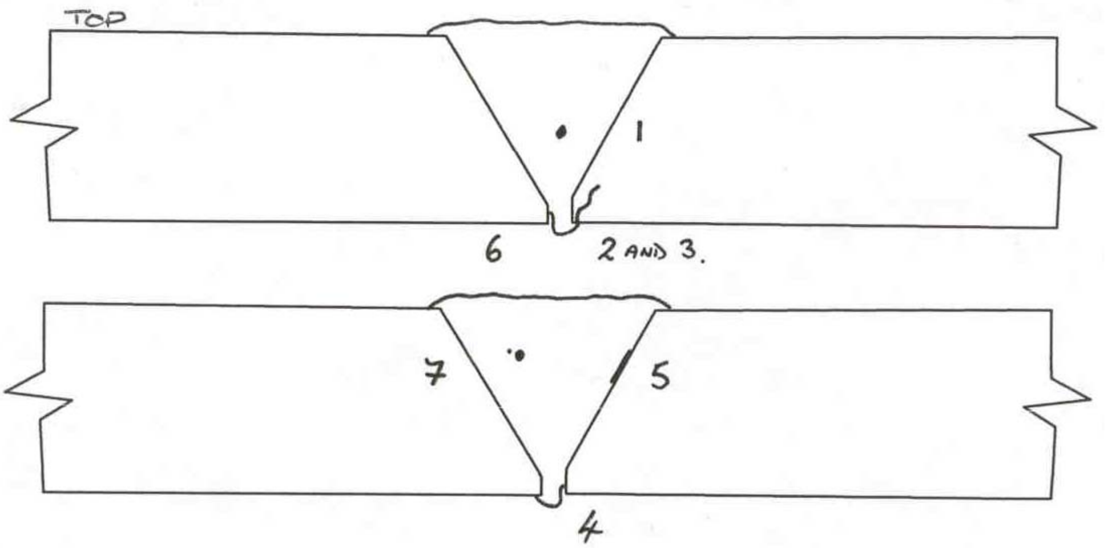
NF = Not found

Table A4.95: Results using 70° single 4MHz probe

A4.2.7 Testsample PL8228

Sample Description

Radiographic sample, 25mm thick. See radiographic results for details.
Weld preparation angle: 30°.



Radiographic Results

Flaw No	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Tungsten inclusion	2	25
2	Root crack	22	60
3	Root crack	15	100
4	Lack of root fusion	30	185
5	Lack of fusion	20	236
6	Lack of root fusion	13	260
7	Tungsten inclusion	4	280
Comments	Sample thickness = 25mm. Sample as welded Note that flaws 1 & 2 are not clearly visible on radiograph.		

Table A4.96: X-rays results

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	NF	NF	NF	NF
2	NF	NF	45	47
3	NF	NF	112	39
4	NF	NF	224	33
5	63	44	40	48
6	100	40	NF	NF
7	NF	NF	NF	NF

NF = Not found

Table A4.97: Results using 45° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	NF	NF	NF	NF
2	36	50	50	47
3	28	52	45	48
4	25	53	80	43
5	NF	NF	25	53
6	80	43	NF	NF
7	NF	NF	NF	NF

NF = Not found

Table A4.98: Results using 45° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	NF	NF	NF	NF
2	NF	NF	70	41
3	NF	NF	178	34
4	NF	NF	141	36
5	NF	NF	251	31
6	112	38	63	43
7	NF	NF	NF	NF

NF = Not found

Table A4.99: Results using 60° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	NF	NF	NF	NF
2	NF	NF	112	37
3	70	41	90	39
4	NF	NF	90	39
5	NF	NF	282	29
6	56	43	NF	NF
7	NF	NF	NF	NF

NF = Not found

Table A4.100: Results using 60° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	NF	NF	NF	NF
2	90	41	159	36
3	112	39	251	32
4	100	40	282	31
5	NF	NF	63	44
6	100	40	NF	NF
7	NF	NF	NF	NF

NF = Not found

Table A4.101: Results using 70° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	NF	NF	NF	NF
2	159	35	112	38
3	100	39	100	39
4	224	32	141	36
5	NF	NF	159	35
6	36	48	112	38
7	NF	NF	NF	NF

NF = Not found

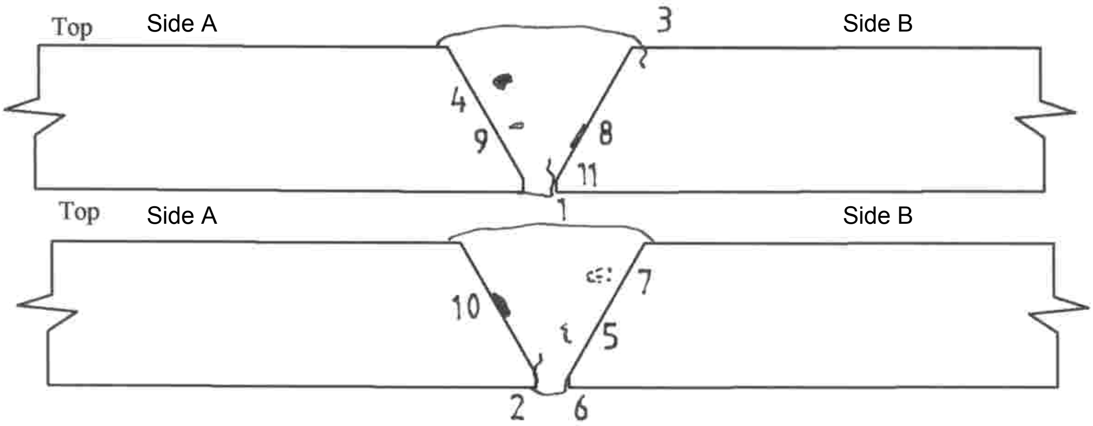
Table A4.102: Results using 70° single 4MHz probe

A4.3. PIPES

A4.3.1 Testsample P8301

Sample Description

Radiographic sample, 35mm thick. See radiographic results for details.
Weld preparation angle: 30°.



Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Intended flaw height (mm)	Distance from datum (mm)
1	Lack of root fusion	27		45
2	Root crack	28		90
3	Toe crack	20		167
4	Slag	19		253
5	Centre line crack	29		405
6	Lack of root fusion	17		450
7	Porosity	25		600
8	Lack of sidewall fusion	38		712
9	Tungsten inclusion	3		780
10	Lack of sidewall fusion	28		840
11	Root crack	25		895
Comments	Radiographic sample. Lack of root fusion defects are not clearly defined. Sample as welded.			

Table A4.103: X-rays results

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	125	22	400	12
2	200	18	112	23
3	159	20	400	12
4	Not Found		14	41
5	63	28	100	24
6	125	22	355	13
7	Not Found		Not Found	
8	Not Found		125	22
9	Not Found		Not Found	
10	Not Found		100	24
11	159	20	159	20

Table A4.104: Results using 45° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	112	39	794	22
2	100	40	100	40
3	80	42	708	23
4	40	48	36	49
5	178	35	178	35
6	40	48	316	30
7	Not Found		10	60
8	50	46	141	37
9	32	50	Not Found	
10	45	47	178	35
11	28	51	90	41

Table A4.105: Results using 45° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	100	30	251	22
2	224	23	100	30
3	90	43*	70	33
4	32	52*	50	48*
5	32	40	80	44*
6	112	29	159	26
7	Not Found		Not Found	
8	100	30	50	36
9	Not Found		Not Found	
10	50	48*	32	40
11	178	25	251	34*

* Use of an extended DAC

Table A4.106:Results using 60° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	141	37	794	22
2	178	35	100	40
3	70	43	100	40
4	18	55	18	55
5	200	54	56	45
6	32	50	40	48
7	Not Found		25	52
8	200	34	112	39
9	32	50	20	54
10	40	48	159	50
11	125	38	178	35

Table A4.107: Results using 60° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	159	28	282	23
2	316	22	125	30
3	Not Found		125	30
4	40	40	20	46
5	70	35	50	38
6	100	32	178	27
7	Not Found		13	50
8	200	26	32	42
9	Not Found		Not Found	
10	100	32	40	40
11	200	26	224	25

Table A4.108: Results using 70° single 2MHz probe

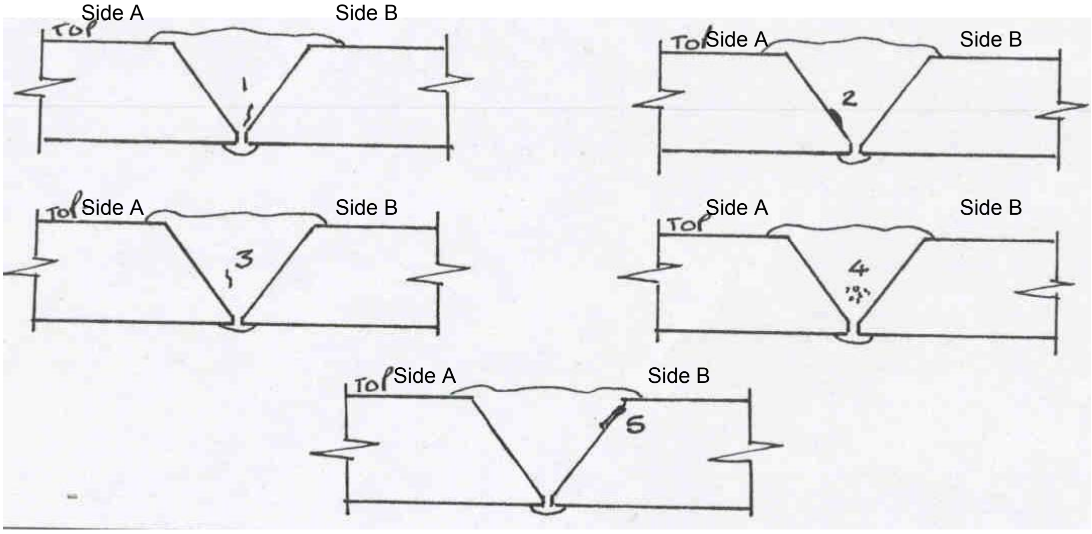
Defect No	Inspection from Side A		Inspection from Side B	
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC
1	224	40	224	40
2	224	40	224	40
3	Not Found		100	47
4	Not Found		Not Found	
5	22	59	25	59
6	224	40	562	32
7	16	63	20	61
8	282	36	36	56
9	Not Found		Not Found	
10	100	47	125	45
11	112	46	90	48

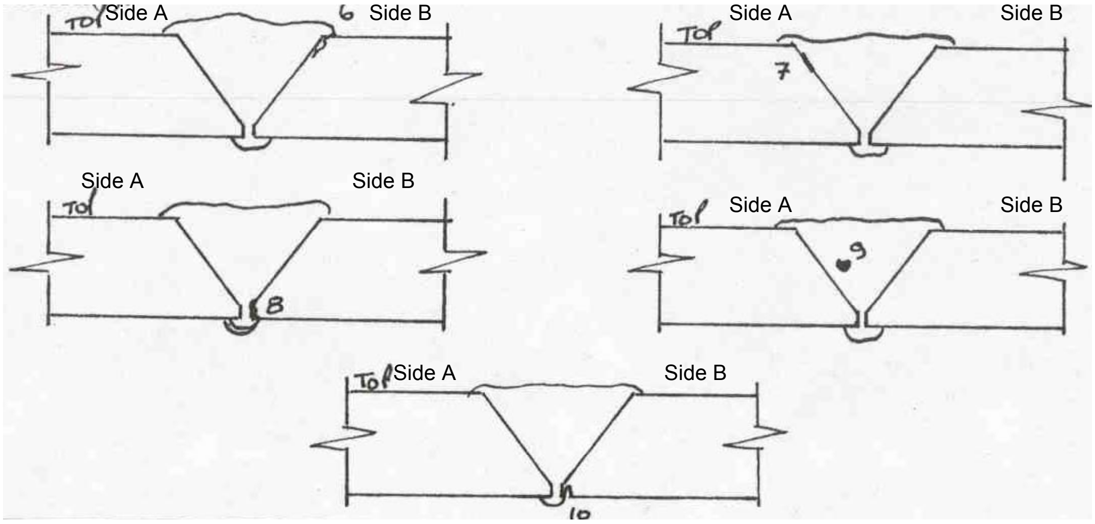
Table A4.109: Results using 70° single 4MHz probe

A4.3.2Testsample TPF6

Sample Description

Flaw No	Flaw Type	Flaw Length (mm)	Intended flaw height (mm)	Distance from datum (mm)
1	Crack	18	3	53
2	LoSWF	10	2	134
3	Crack	14	3	212
4	Porosity	20	3	262
5	LoSWF	18	3	336
6	Toe crack	17	3	478
7	LoSWF	12	3	562
8	Root crack	18	3	629
9	Slag	12	1-2	695
10	Root undercut	14	2	762
Comments	Sample thickness = 12.5mm, OD = 457mm. Weld preparation angle: 37.5°. Sample as welded.			





Radiographic Results

Flaw No.	Flaw characterised as	Flaw Length (mm)	Distance from datum (mm)
1	Crack	20	55-75
2	Not reported		
3	Slag*	10	215-225
4	Porosity	20	270-290
5	Not reported		
6	Suspected crack	20	480-500
7	Porosity*	50	550-600
8	Crack	20	635-655
9	LoSWF*	10	700-710
10	LoRF	20	770-780
Comments	T/Inclusion at 300. Porosity at 55-75 & 1005-1010. Piping at 1005-1007. * Defect characterisation not as expected. Note that an independent review of the radiographs was carried out for these three defects by a second inspector. The operator concurs with the original interpretation of these flaws. • Flaw 3 - Slag – Note that the crack may be associated with the slag inclusion, but no crack characteristics like were viewed, even under magnification. • Flaw 7 - Porosity – Note that the intended LOSWF may have been missed altogether radiographically due to its orientation in relation to the beam axis. • Flaw 9 - Lack of fusion – The first inspector called this defect a LOSWF, this is a subjective interpretation as it is difficult to specifically place LOF within the weld volume on a 2D radiographic image. Lack of fusion by its very nature of being a planar defect is normally cause for rejection wherever it occurs within the weld volume, therefore not normally required to categorise type.		

Table A4.110: X-rays results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Crack	20	55-75
2	Not reported		
3	Slag*	10	215-225
4	Porosity	20	270-290
5	Not reported		
6	Suspected crack	20	480-500
7	Porosity*	50	550-600
8	Crack	20	635-655
9	LoSWF*	10	700-710
10	LoRF	20	770-780
Comments	T/Inclusion at 300. Porosity at 55-75 & 1005-1010. Piping at 1005-1007. * Defect characterisation not as expected. Note: The results from γ-rays and x-rays were independently analysed. Both results are the same.		

Table A4.111: γ-rays results

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NR	NR	NR	NR	NR	NR
2	159	24	NR	NR	11	133
3	159	24	NR	NR	7	217
4	NR	NR	14	45	16	266
5	NR	NR	178	23	15	335
6	NR	NR	159	24	17	478
7	125	26	NR	NR	11	563
8	NR	NR	NR	NR	NR	NR
9	125	26	50	34	12	695
10	NR	NR	NR	NR	NR	NR

NR = Not Reported

Table A4.112: Results using 45° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	NR	NR	NR	NR	NR	NR
2	50	41	NR	NR	12	132
3	63	39	NR	NR	9	215
4	NR	NR	10	55	15	265
5	NR	NR	80	37	15	336
6	NR	NR	36	36	18	477
7	70	38	NR	NR	10	563
8	NR	NR	NR	NR	NR	NR
9	56	40	10	55	13	695
10	NR	NR	NR	NR	NR	NR

NR = Not Reported

Table A4.113: Results using 45° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	11	49	90	31	17	53
2	125	28	NR	NR	12	132
3	70	33	NR	NR	13	211
4	14	47	32	40	22	262
5	32	40	200	24	19	334
6	100	30	63	34	19	477
7	200	24	NR	NR	14	562
8	32	40	125	28	21	628
9	63	34	40	38	13	695
10	NR	NR	18	45	11	759

NR = Not Reported

Table A4.114: Results using 60° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	32	46	90	37	17	55
2	112	35	NR	NR	14	131
3	70	39	NR	NR	13	212
4	20	50	22	49	20	262
5	20	50	141	33	17	335
6	56	41	80	38	18	477
7	141	33	NR	NR	14	561
8	38	38	40	44	20	627
9	50	42	50	42	12	695
10	NR	NR	32	46	10	760

NR = Not Reported

Table A4.115: Results using 60° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	100	30	112	29	19	54
2	100	30	56	35	13	131
3	141	27	45	37	14	213
4	28	41	18	45	20	260
5	200	24	56	35	20	335
6	50	36	40	28	20	474
7	56	35	178	25	13	560
8	141	27	316	20	24	631
9	80	32	63	34	10	696
10	NR	NR	NR	NR	NR	NR

NR = Not Reported

Table A4.116: Results using 70° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	63	38	200	28	18	54
2	90	35	36	43	11	130
3	45	41	25	46	17	212
4	18	49	18	49	21	261
5	36	43	32	44	17	335
6	20	48	45	41	20	474
7	25	46	125	32	12	562
8	112	33	70	37	22	630
9	36	43	70	37	13	695
10	NR	NR	7	57	12	758

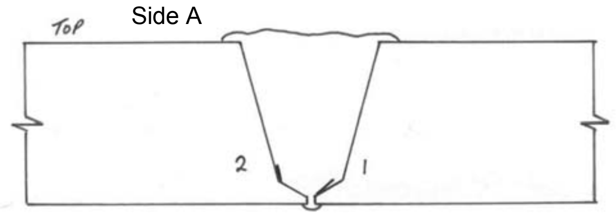
NR = Not Reported

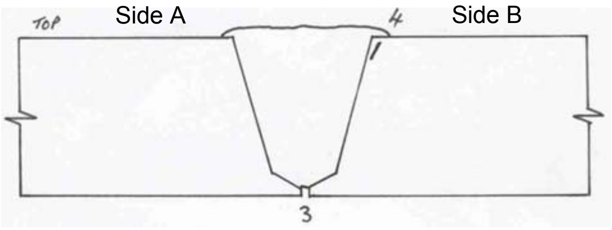
Table A4.117: Results using 70° single 4MHz probe

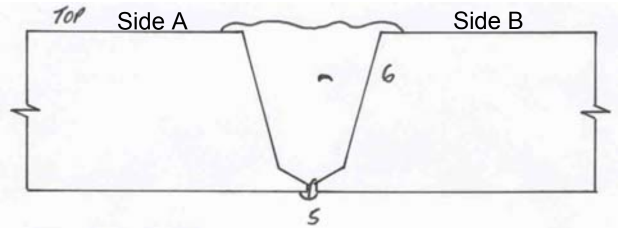
A4.3.3 Testsample TPF8

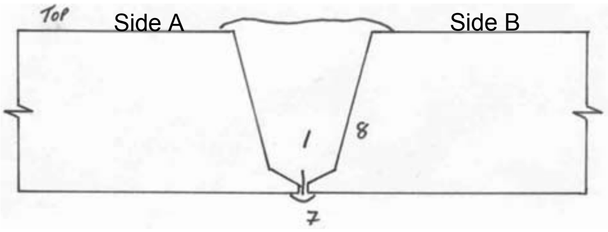
Sample Description

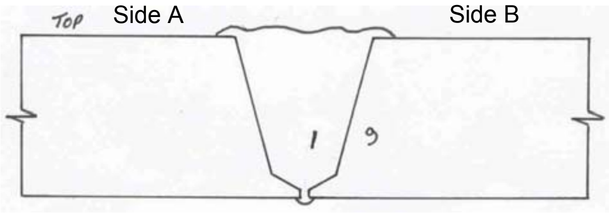
Flaw No	Flaw Type	Flaw Length (mm)	Intended flaw height (mm)	Distance from datum (mm)
1	LoSWF	22	4	33
2	LoSWF	22	4	144
3	Lack of root penetration	21	2	256
4	HAZ crack	16	4	368
5	Root crack	18	2	451
6	Lack of inter-run fusion	5	2	572
7	Tight planar smooth root defect	20	6	672
8	Rough planar	18	4	767
9	Rough planar	15	4	859
10	Rough planar	14	4	960
11	Root crack	18	4	1048
Comments	Sample thickness = 35mm, OD = 355mm. Weld preparation angles: upper angle = 15°, lower angle = 60°. Sample as welded.			

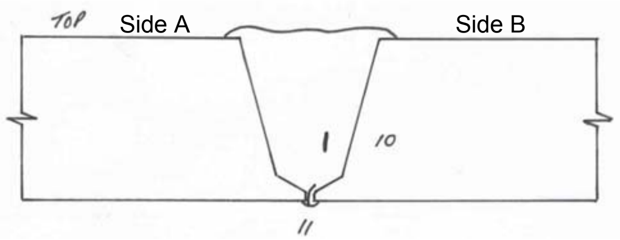












Radiographic Results

Flaw No.	Flaw Type	Flaw Length (mm)	Distance from datum (mm)
1	Not reported		
2	Not reported		
3	LoF	25	260
4	Crack	10	370
5	Not reported		
6	Not reported		
7	Not reported		
8	Pores*	50	750
9	Crack	15	875**
10	Not reported		
11	Slag	10	1050
Comments	* Defect No8 not reported. Pores reported at the same circumferential position. ** Defect No9 could have been misplaced. The examination of the radiographs by another inspector provide a more expected result: distance from datum of 860mm to 879mm. Note that a second examination of the radiographs show that the results, with the exception of defect No9 (see above), are as reported in the table.		

Table A4.118: γ-rays results

Ultrasonic Results

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	112	29	159	26	26	33
2	25	42	NR	NR	20	144
3	355	19	316	20	22	256
4	NR	NR	50	36	16	368
5	100	30	80	32	20	451
6	NR	NR	NR	NR	NR	NR
7	282	21	224	23	21	672
8	NR	NR	70	33	19	767
9	32	40	45	37	17	860
10	100	30	40	38	17	960
11	100	30	224	23	19	1048

NR = Not Reported

Table A4.119: Results using 45° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	80	38	125	34	25	33
2	NR	NR	NR	NR	NR	NR
3	125	34	251	28	23	256
4	NR	NR	50	42	17	368
5	90	37	56	41	20	451
6	NR	NR	NR	NR	NR	NR
7	125	34	125	34	21	672
8	NR	NR	50	42	20	767
9	32	46	25	48	17	860
10	90	37	16	52	17	960
11	70	39	159	32	17	1048

NR = Not Reported

Table A4.120: Results using 45° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	112	32	100	33	26	33
2	16	49	28	44	24	144
3	159	29	224	26	22	256
4	NR	NR	56	38	18	256
5	178	28	80	35	17	451
6	NR	NR	NR	NR	NR	NR
7	400	21	316	23	20	672
8	90	34	63	37	20	767
9	112	32	90	34	19	860
10	70	36	25	45	18	960
11	125	31	125	31	17	1048

NR = Not Reported

Table A4.121: Results using 60° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	80	40	100	38	26	33
2	20	52	25	50	24	144
3	159	34	200	32	23	256
4	NR	NR	28	49	18	368
5	125	36	80	40	19	451
6	NR	NR	NR	NR	NR	NR
7	631	22	316	28	19	672
8	70	41	70	41	20	767
9	80	40	80	40	21	859
10	80	40	40	46	18	960
11	125	36	251	30	17	1048

NR = Not Reported

Table A4.122: Results using 60° single 4MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	112	33	125	32	22	33
2	NR	NR	28	45	24	144
3	224	27	159	30	20	256
4	NR	NR	100	34	16	368
5	200	28	159	30	20	451
6	NR	NR	NR	NR	NR	NR
7	501	20	224	27	20	672
8	141	31	32	44	19	767
9	100	34	63	38	21	860
10	80	36	70	37	17	960
11	159	30	100	34	22	1048

NR = Not Reported

Table A4.123: Results using 70° single 2MHz probe

Defect No	Inspection from Side A		Inspection from Side B		Flaw Length (mm)	Distance from datum (mm)
	% DAC	Signal dB Gain to DAC	% DAC	Signal dB Gain to DAC		
1	141	36	100	39	20	33
2	9	60	45	46	21	144
3	224	32	282	30	17	256
4	NR	NR	40	47	16	368
5	251	31	125	37	18	451
6	NR	NR	NR	NR	NR	NR
7	400	27	251	31	22	672
8	178	34	36	48	17	767
9	125	37	125	37	22	861
10	63	43	45	46	17	961
11	125	37	159	35	18	1048

NR = Not Reported

Table A4.124: Results using 70° single 4MHz probe

ANNEX A5: SEMI-AUTOMATIC INSPECTION RESULTS

A5.1. REPORT OF SEMI-AUTOMATED ULTRASONIC TEST

Technology
Porterfield Road
Renfrew, United Kingdom
PA4 8DJ
Telephone: +44 (0)141 886 4141

Report No: **PH/SAUT11/04**	SHEET 1 OF 1
Client: HSE	
Test Location: Mitsui Babcock Technology Centre, Renfrew	
Contract Name: Replacement of RT by UT	
Project/Sub-Project/Activity: 79148/SD001/150	
Test Date(s): 15/03/04 – 08/04/04	

REPORT OF SEMI-AUTOMATED ULTRASONIC TEST

Section 1 - Component Details

Component: TPF 8	Manufacturing Stage:
Dimensions: 355mm OD x 35mm thick	Drawing No:
Surface Condition: As Welded	Material: ST52.0 Carbon Steel

Section 2 - Equipment Details

System Type: SMARRT-Scan Flaw Detector Unique ID: NT/B/FC0018	Scanner Type: Belt. Couplant: UCA-2 (diluted).
Calibration Block Type: Universal 50mm Calibration Block Unique ID: FC10	Reference Block Type: BS3923 Reference Block Unique ID: FR

PROBE	Unique ID	S257	S256	9011		9012		
DETAILS	Wave Mode	Shear	Shear	Comp.	Shear	Shear	Shear	
	Angle °	70	70	70	31	70	31	
	Frequency (MHz)	2	2	4		4		
	Crystal size (mm)	Ø10	Ø10	Ø10		Ø10		
	Twin or Single	Single	Single	Single		Single		
	Focal range (mm)	N/A	N/A	N/A		N/A		
							Equipment complies with TC-4212-OP	YES

Section 3 - Inspection Details

Reference Sensitivity dB	45	18	30	30	
Scanning Sensitivity dB	Various – refer to set up file.				

Sensitivity References: 3mm SDH

Test Limitations/Remarks:

Inspection Procedure: TC-4810-OP	Issue No. 2	Acceptance Standard: N/A	Issue No.
Technique Sheet: TC-4811-OP	Issue No. 1		

Section 4 - Inspection Result

Inspection performed under open trial conditions. 10 of the 11 intended defects in TPF8 were clearly detected. Defect no.6 was not detected.

The SMARRT-Scan data (defect images) are presented in Annex A5.2.

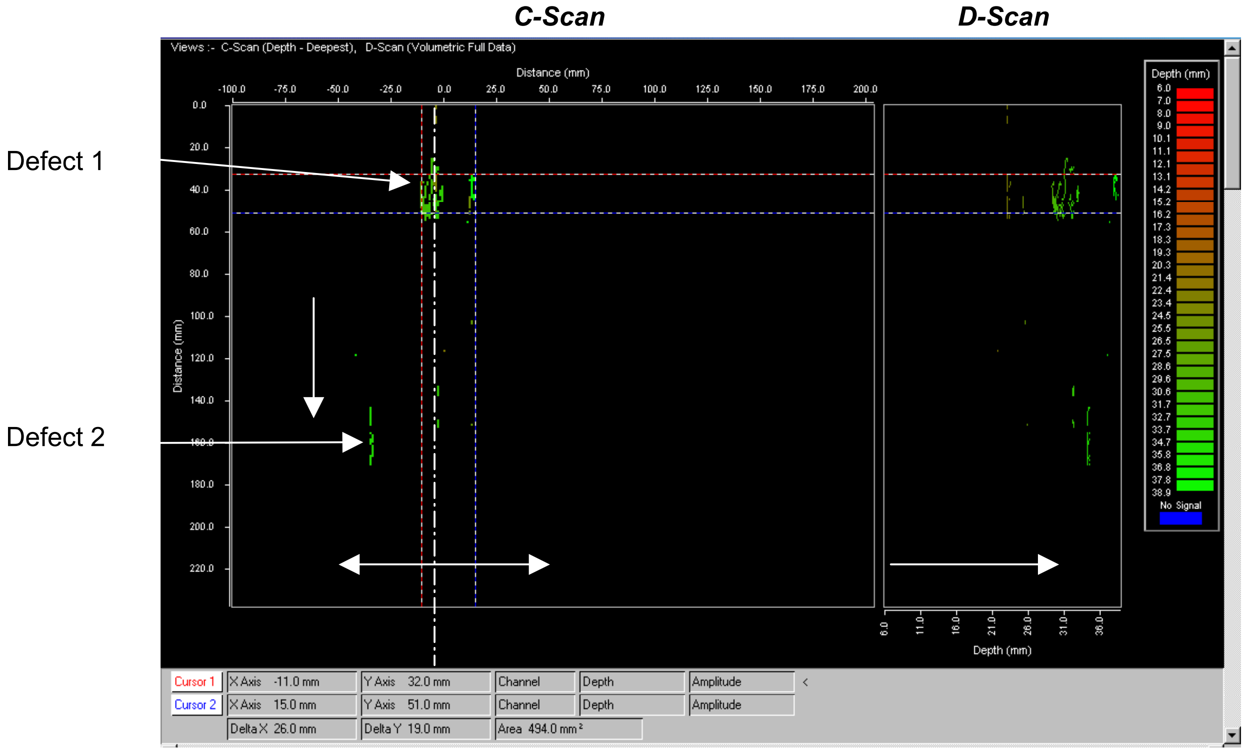
A summary comparison of the SMARRT-Scan data versus testpiece manufacturer's data is presented in Annex A5.3.

A photograph of the scanner set up is presented in Annex A5.4.

Signatory	**Name**	**Job Title**	**PCN Number**	**Signature**	**Date**
Tested by:	E M Karlsson	NDT Project Engineer	210812		
Approved by:	F E Hardie	NDT Group Leader Level 3	113354		
Client (if required):					

A5.2 SMARRT-SCAN DATA (DEFECT IMAGES)

Defect 1

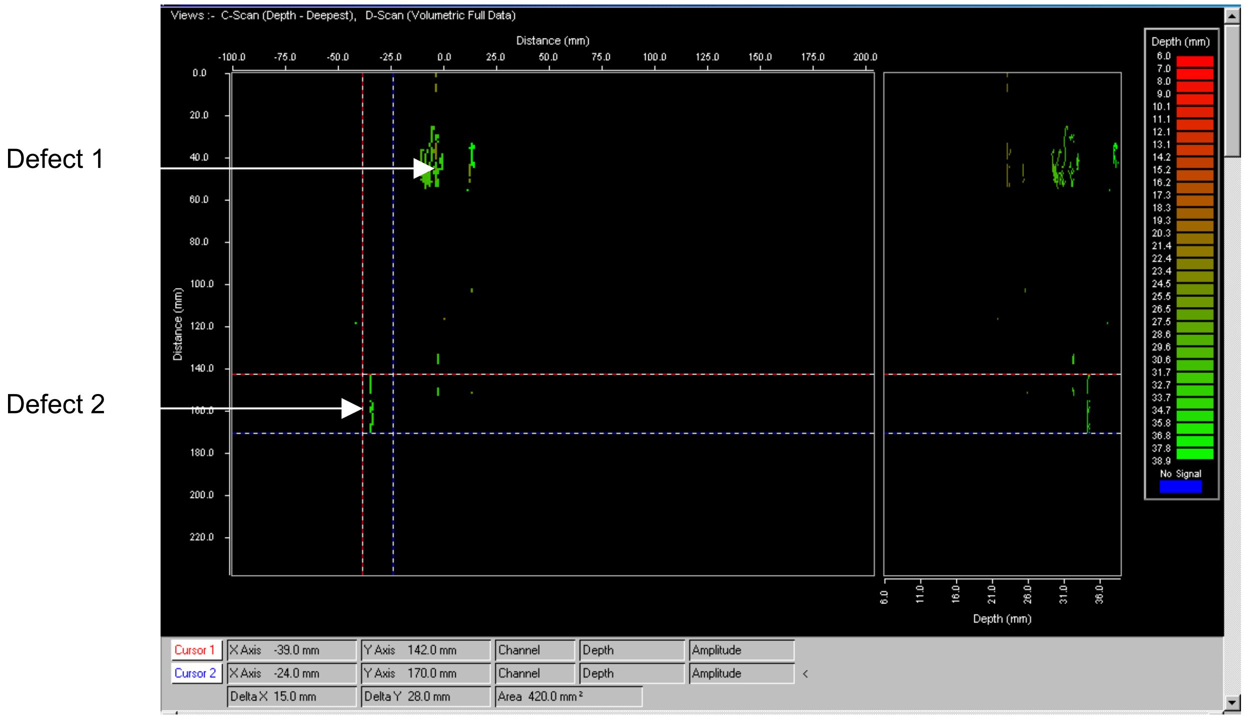


Views :- C-Scan (Depth - Deepest), D-Scan (Volumetric Full Data)

Cursor 1 | X Axis -11.0 mm | Y Axis 32.0 mm | Channel | Depth | Amplitude
Cursor 2 | X Axis 15.0 mm | Y Axis 51.0 mm | Channel | Depth | Amplitude
Delta X 26.0 mm | Delta Y 19.0 mm | Area 494.0 mm²

Defect 1 is located around the weld centreline at a depth of ≈30mm.

Defect 2

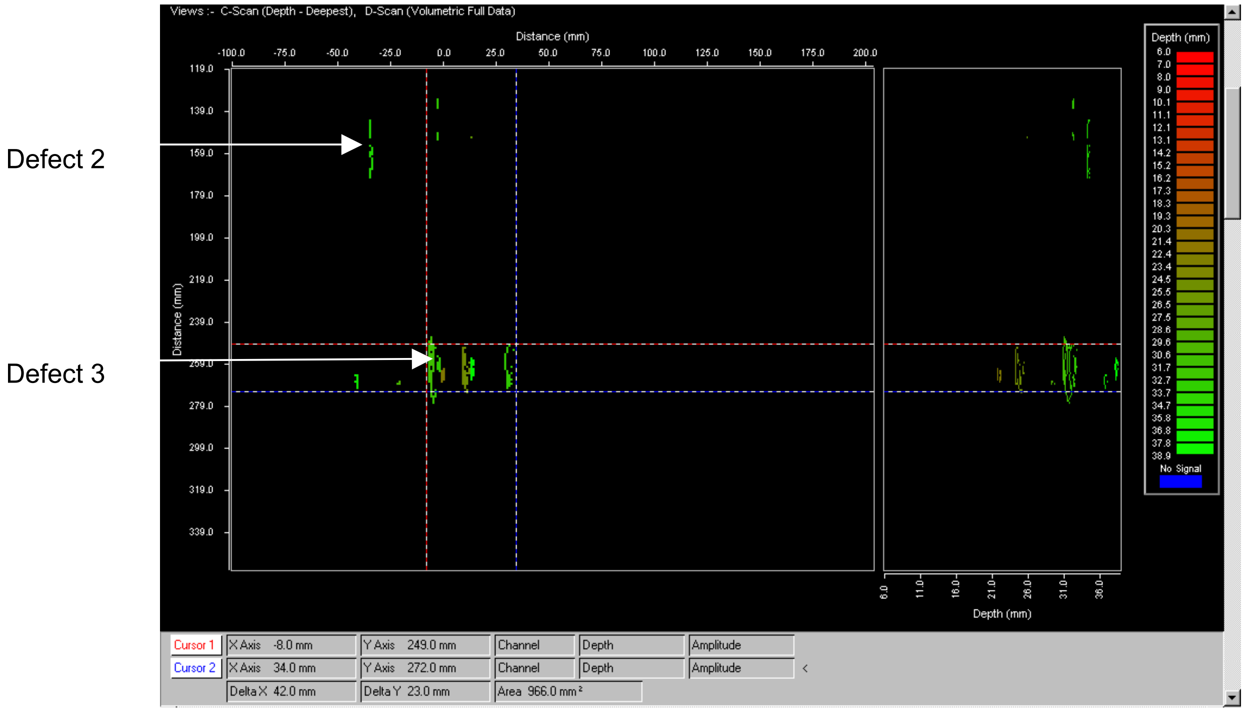


Views :- C-Scan (Depth - Deepest), D-Scan (Volumetric Full Data)

Cursor 1 | X Axis -39.0 mm | Y Axis 142.0 mm | Channel | Depth | Amplitude
Cursor 2 | X Axis -24.0 mm | Y Axis 170.0 mm | Channel | Depth | Amplitude
Delta X 15.0 mm | Delta Y 28.0 mm | Area 420.0 mm²

Defect 2 is located slightly away from the weld centre at a depth of 34mm.

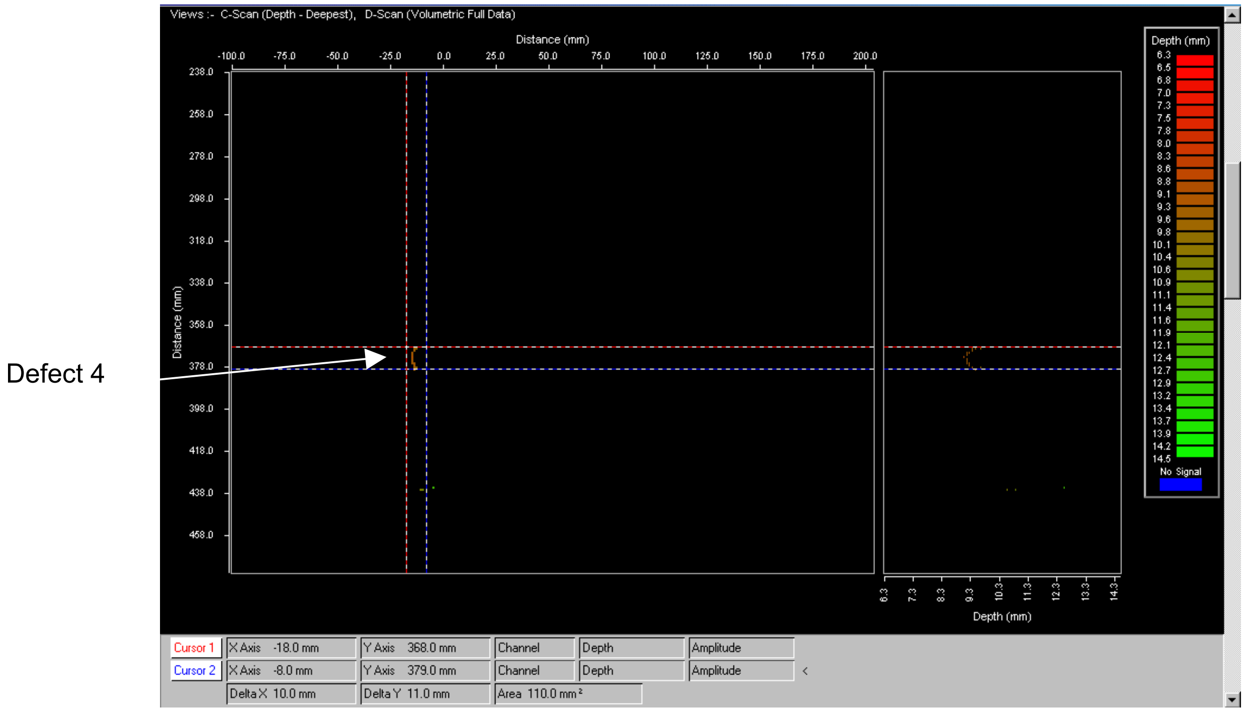
Defect 3



Cursor 1 | X Axis -8.0 mm | Y Axis 249.0 mm | Channel | Depth | Amplitude
Cursor 2 | X Axis 34.0 mm | Y Axis 272.0 mm | Channel | Depth | Amplitude
Delta X 42.0 mm | Delta Y 23.0 mm | Area 966.0 mm²

Defect 3 is located at a depth between 25mm and 30mm deep around the weld centreline.

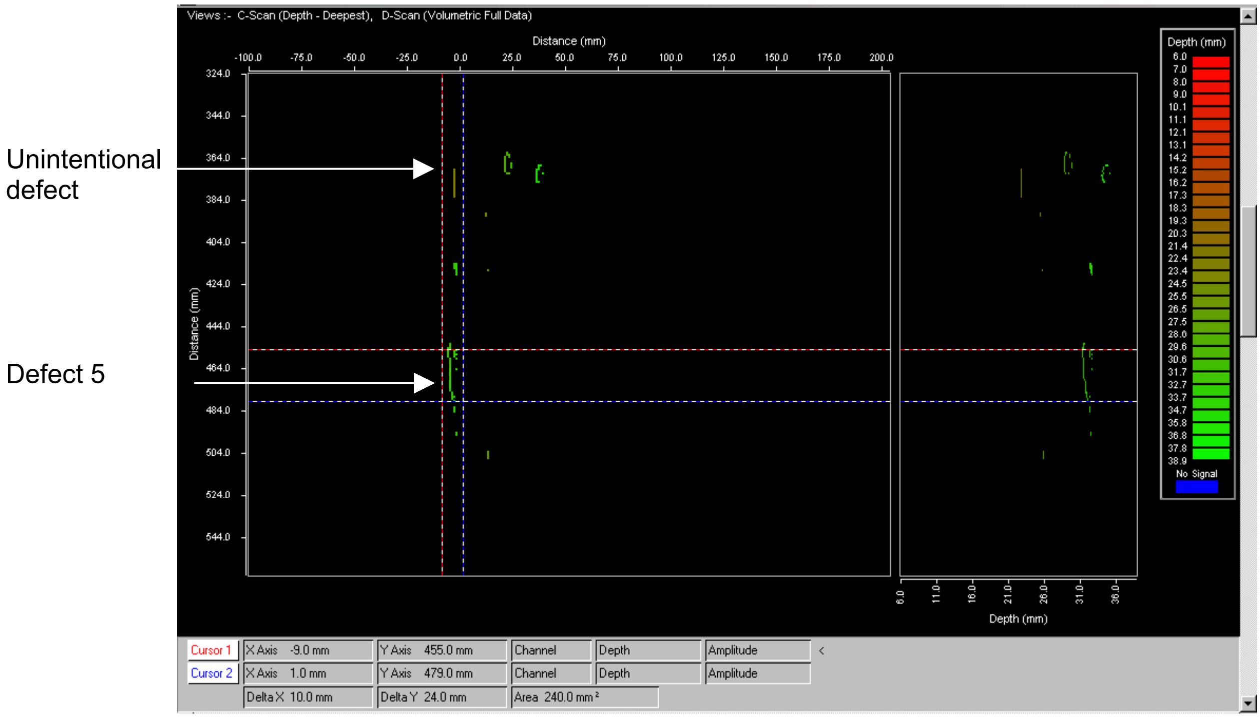
Defect 4



Cursor 1 | X Axis -18.0 mm | Y Axis 368.0 mm | Channel | Depth | Amplitude
Cursor 2 | X Axis -8.0 mm | Y Axis 379.0 mm | Channel | Depth | Amplitude
Delta X 10.0 mm | Delta Y 11.0 mm | Area 110.0 mm²

Defect 4: Pulse-echo signal at the edge of the weld about 8mm deep.

Defect 5



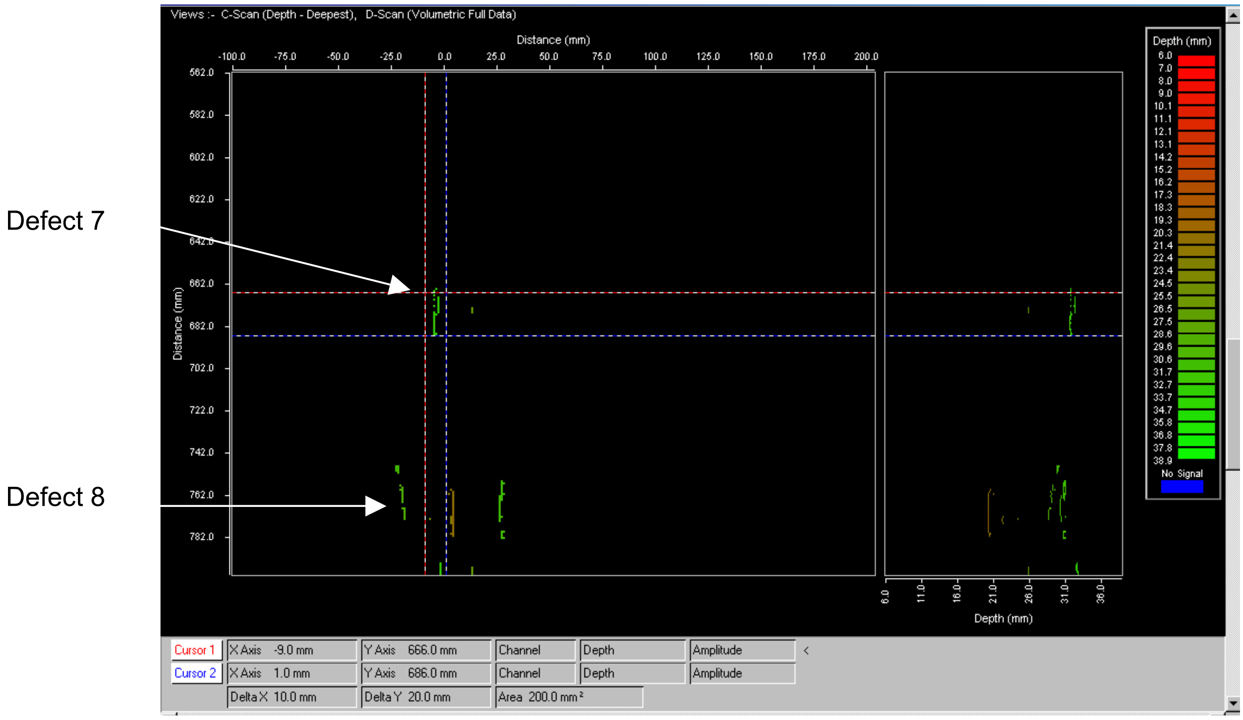
Cursor 1 | X Axis -9.0 mm | Y Axis 455.0 mm | Channel | Depth | Amplitude

Cursor 2 | X Axis 1.0 mm | Y Axis 479.0 mm | Channel | Depth | Amplitude

Delta X 10.0 mm | Delta Y 24.0 mm | Area 240.0 mm²

Defect 5 is located around the weld centreline at a depth of around 32mm.

Defect 7



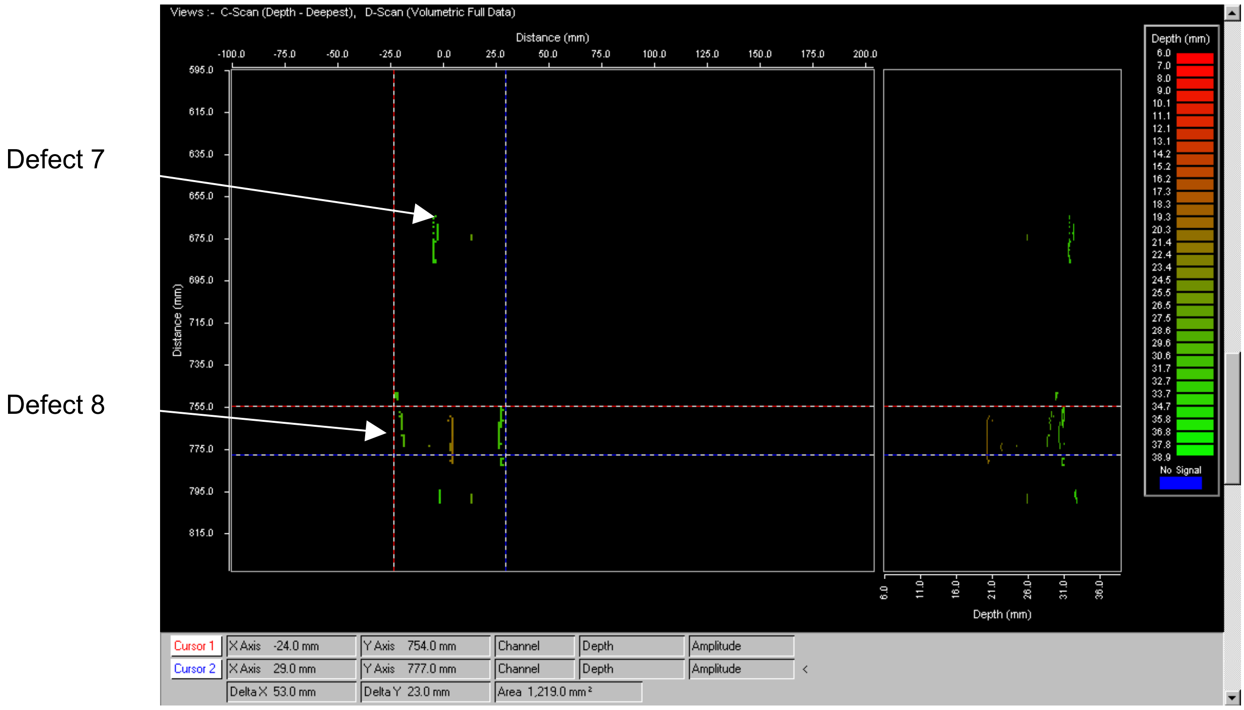
Cursor 1 | X Axis -9.0 mm | Y Axis 666.0 mm | Channel | Depth | Amplitude

Cursor 2 | X Axis 1.0 mm | Y Axis 686.0 mm | Channel | Depth | Amplitude

Delta X 10.0 mm | Delta Y 20.0 mm | Area 200.0 mm²

Defect 7 is locatedaround the weld centreline at a depth of 33mm.

Defect 8



Cursor 1	X Axis -24.0 mm	Y Axis 754.0 mm	Channel	Depth	Amplitude
Cursor 2	X Axis 29.0 mm	Y Axis 777.0 mm	Channel	Depth	Amplitude
	Delta X 53.0 mm	Delta Y 23.0 mm	Area 1,219.0 mm²		

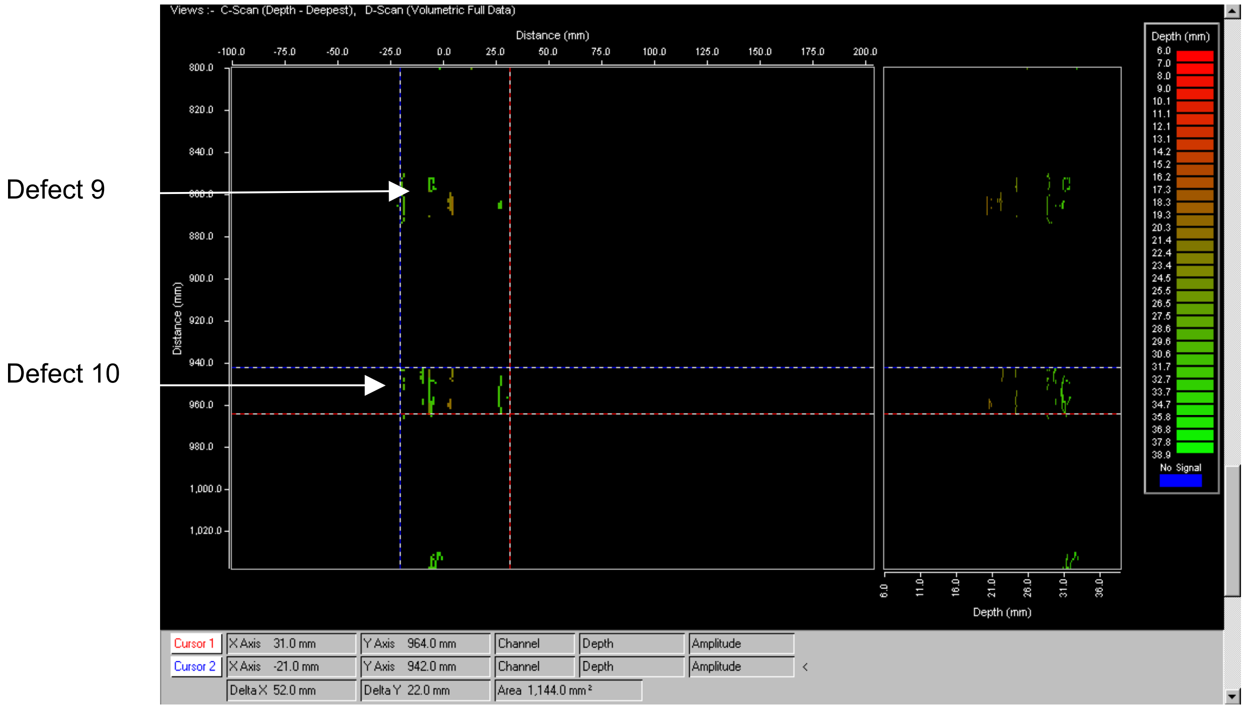
Defect 8 is located at a depth between 21mm and 31mm.

Defect 9

Cursor 1	X Axis -22.0 mm	Y Axis 854.0 mm	Channel	Depth	Amplitude
Cursor 2	X Axis 29.0 mm	Y Axis 869.0 mm	Channel	Depth	Amplitude
	Delta X 51.0 mm	Delta Y 15.0 mm	Area 765.0 mm²		

Defect 9 is located at a depth between 22mm and 31mm.

Defect 10


Views :- C-Scan (Depth - Deepest), D-Scan (Volumetric Full Data)

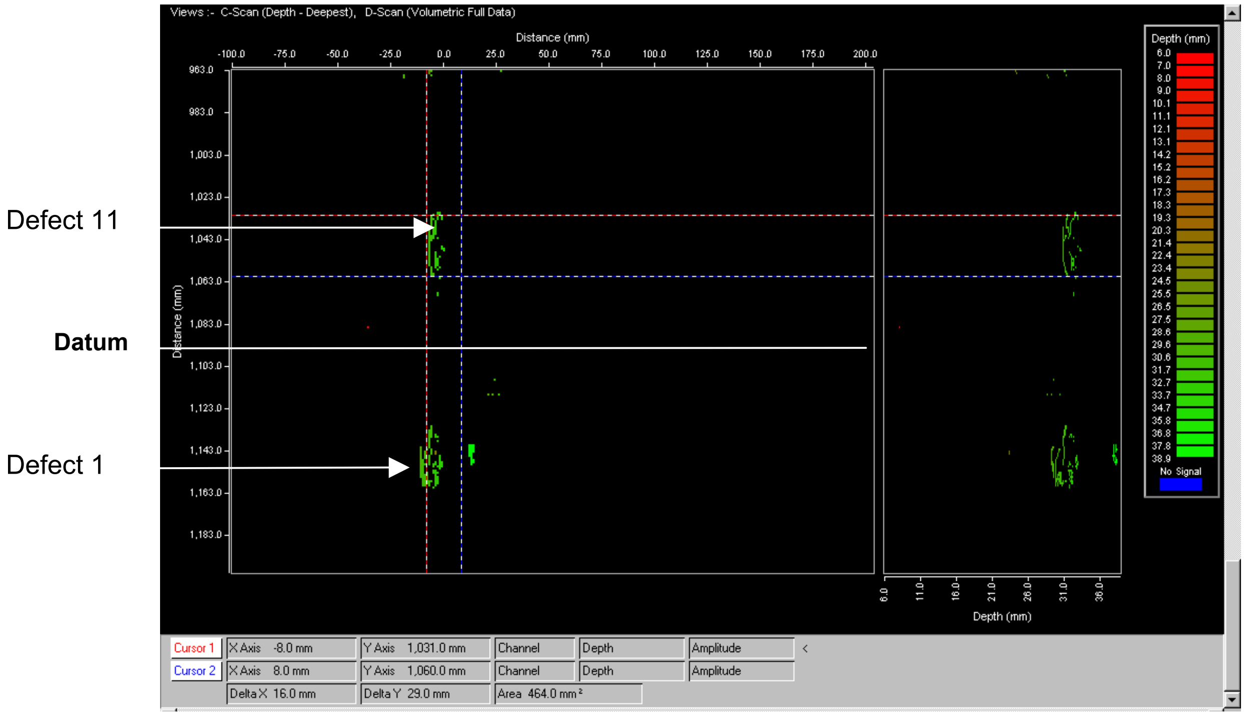
Cursor 1 | X Axis 31.0 mm | Y Axis 964.0 mm | Channel | Depth | Amplitude

Cursor 2 | X Axis -21.0 mm | Y Axis 942.0 mm | Channel | Depth | Amplitude

Delta X 52.0 mm | Delta Y 22.0 mm | Area 1,144.0 mm²

Defect 10 is located at depths between 21mm and 31mm deep.

Defect 11


Views :- C-Scan (Depth - Deepest), D-Scan (Volumetric Full Data)

Cursor 1 | X Axis -8.0 mm | Y Axis 1,031.0 mm | Channel | Depth | Amplitude

Cursor 2 | X Axis 8.0 mm | Y Axis 1,060.0 mm | Channel | Depth | Amplitude

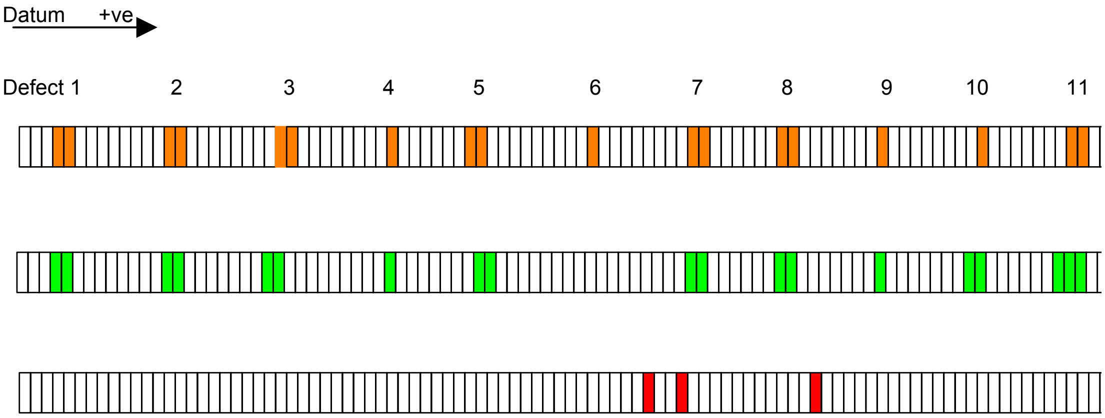
Delta X 16.0 mm | Delta Y 29.0 mm | Area 464.0 mm²

Defect 11 is located around the weld centreline close to full depth of 35mm.

A5.3 COMPARISON OF THE SMARRT-SCAN RESULTS WITH INTENDED DEFECT LOCATIONS

Details of defect positions and lengths				
Flaw No.	Position (D + mm)		Length (mm)	
	Manufacturer	Semi-auto UT	Manufacturer	Semi-auto UT
1	33	32	22	19
2	144	142	22	28
3	256	249	21	23
4	368	368	16	11
5	451	455	18	24
6	572	Not detected	5	Not detected
7	672	666	20	20
8	767	754	18	23
9	859	854	15	15
10	960	942	14	22
11	1048	1031	18	29

Relative circumferential positions of defects



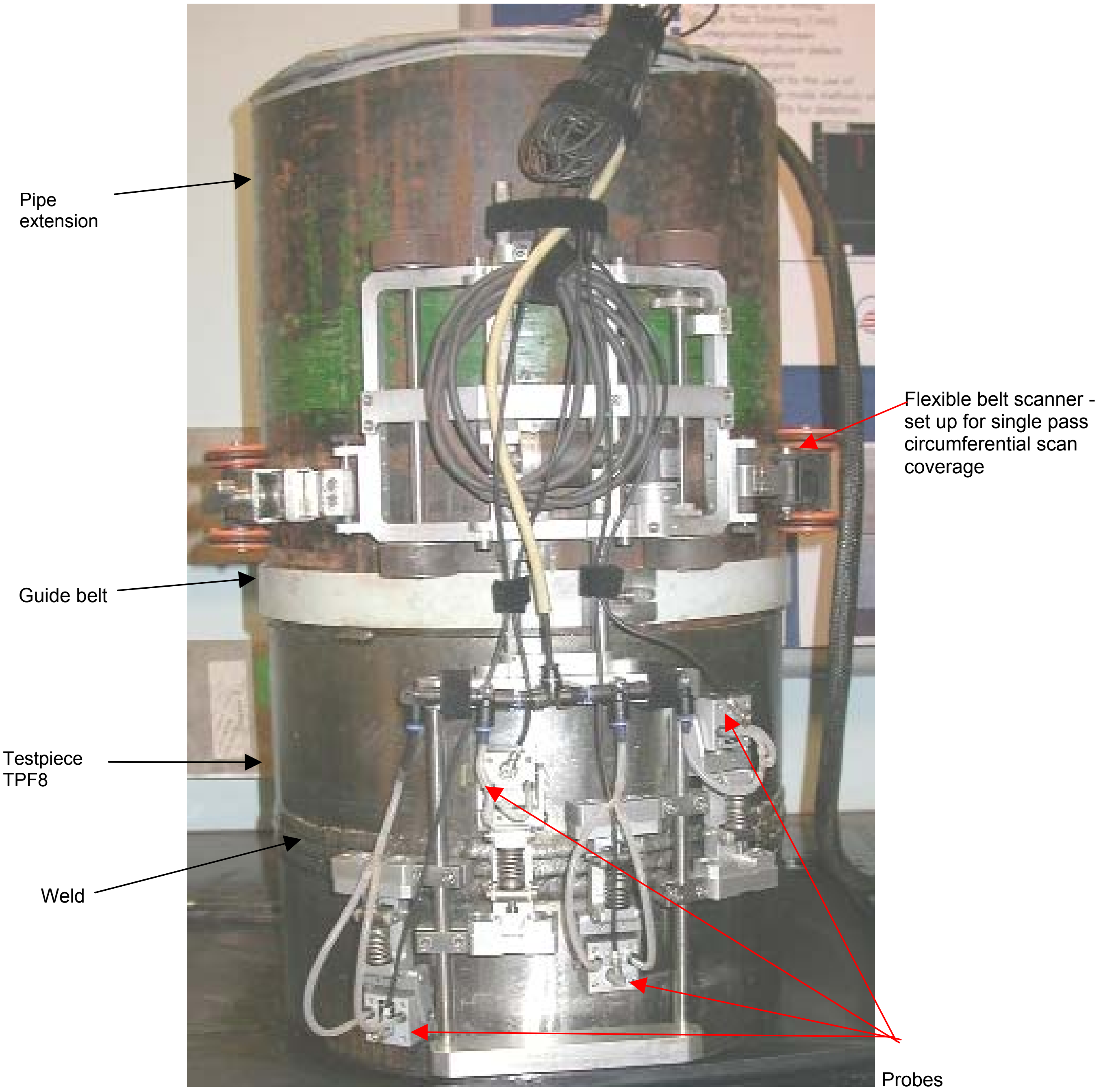
🟧 M Testpiece manufacturer's information

🟩 SMARRT-Scan results

🟥 Additional indications (potentially unintentional defects) recorded by SMARRT-Scan

A5.4 PHOTOGRAPH OF THE SCANNER SET-UP

Scanner set up for TPF8



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