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Compilation of NDE effectiveness data

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Contributors

S. Crutzen	EC, JRC - IAM, Petten, The Netherlands
F. Frank	“
L. Fabbri	“
P. Lemaitre	“
Q. Schneider	TWI, Cambridge, UK
W. Visser	Visser Consultancy Ltd, Weybridge, UK

Table of content

List of Acronyms

CRP:	correct rejection probability
DAC:	distance amplitude correction (ultrasonic calibration curve)
FDP:	flaw detection probability
GVD:	‘generally’ volumetric defect
EBW:	electron beam welding
HF:	human factors
IGSCC:	Intergranular stress corrosion cracking
IGA:	Intergranular attack
MSAW:	metallic submerge arch welding
NGBW:	nitrogen gas beam welding
PPD:	perpendicular planar defect
POD:	probability of detection
VTD:	volumetric type defect

1. OBJECTIVES OF THE COMPILATION

Inspection procedures based on NDE are playing an important role in structural integrity assessment. Plant life management relies in part on inspection. Ageing of installations and wishes to extend their life increase the importance of NDE techniques used to evaluate the state of the structure.

Inspection procedures are a mix of NDE techniques, setting procedures or calibrating principles, decision steps, scanning systems, recording and illustration tools and software.

Inspection procedures often involve information interpretation of indications relying on the skill of the operator.

Inspection procedures are thus not measurement techniques and their performances in defect detection, location, classification and sizing cannot be represented by simple confidence intervals.

WHAT IS NEEDED ?

To be able to use NDE inspection data in a structural integrity assessment reasoning or model, thinking mainly of the needs of small and medium enterprises (SMEs), it is essential to understand :

- all the defects above a certain size were detected and reported ?
- how precise are the given sizes in depth and in length ?

The present compilation aims to answer these two questions for usual heavy duty structural components. It does not try to be precise and exhaustive. On the contrary the objective is to give engineering trends, average values, reasonable uncertainties that can be understood by the structural integrity engineer and introduced in component / defect assessment tools to be handled by SMEs.

Many other subsidiary questions exist :

- what is the detection probability of defects of a certain size ?
- what is the capability of defect location ?
- what is the capability of defect classification ?
- what is the defect sizing accuracy ?
- what is the probability of false alarm ?

HOW TO GET IT ?

The proposed values are delivered from a digest of blind test results or from parametric studies conducted by independent institutions and not from expert declarations.

2. CAPABILITY, EFFECTIVENESS AND RELIABILITY of INSPECTION PROCEDURES

Reliability of inspection procedures based on NDE techniques is made of three constitutive elements which are important to be defined correctly to understand the meaning of NDE evaluations and to use NDE reliability data correctly in view of structural integrity assessment.
During the “ American / European seminar on NDE validation “ at BAM, Berlin in June 1997, the relation between these elements was summarised by a formula accepted by all partners in particular by the US and EU Aeronautic and Nuclear industry representatives:

$$R = f(IC) - g(AP) - h(HF)$$

R = reliability or total performance
IC = intrinsic capability of techniques / procedures
AP = application
HF = human factors

The fact that the inspection is conducted on the right component or part of the component where defects can develop, is not considered here.

In NDE evaluation trials (PISC), the IC aspect is the main aspect considered; human factors are often corrected. In several cases, IC and AP are combined.
In the USA, the whole of R is considered globally, most of the time.

IC is considered by analytical models. Some aspects of AP can be considered e.g. counterbore. Now, some statistical models try to obtain the overall POD, including HFs.

This difference of concepts is, the essential difference between the American and the European approaches to inspection qualification :

- in the USA, ASME Appendix 8 considers that all three elements are difficult to separate ;
- in Europe, ENIQ separates the elements and tackles first the aspects of capability and application features, independently from the human interaction.

As human factor effects are not really predictable, and are notoriously difficult to quantify, discussion or use of NDE reliability data can be misleading. What counts first is the knowledge of the effectiveness of the inspection, that could be defined as being

$$E = f(IC) - g(AP)$$

The human factor must be controlled by a quality assurance programme, knowing that the operator effect could reduce the reliability of total performance to as little as zero in case of adverse situations, distraction or demotivation.

The present report considers thus mainly inspection effectiveness and not inspection reliability.

This inspection effectiveness is, in turn, considered with particular reference to the value and limits of the intrinsic capability of the techniques. The limiting function g(AP) of the parameters of the application such as access, surface roughness and noise level depends on the situation or globally on the industrial branch considered: aeronautics, petrochemical, off-shore, …

3. DEFECTS, COMPONENTS, INSPECTION TECHNIQUES, VARIABLES.

3.1. Introduction

An inspection procedure based on NDE techniques is a process involving many (up to 22 in PISC) individual techniques, decision steps, calibration rules, indication treatments, reporting guidelines, …

To allow a pragmatic presentation of inspection procedures effectiveness or performance in detection and sizing of flaws, several categories of components are considered. Such groups were selected by the Task Group 3 of SINTAP. Emphasis is put on planar type defects.

The inspection procedures themselves are also categorised in groups corresponding to the families of inspection procedures often typical of industry branches such as petrochemical, energy production, aeronautics, …

Variables needed for the presentation of results are the ones used for the presentation of PISC, NIL and other NDE reliability assessment exercises

3.2. Defect families

Defects are of all kinds but effectiveness of NDT refers mainly to planar type defects , close to perpendicular to the surface (tilt angle from -30 to +30 deg). Either they require specific NDE techniques to be detected and sized correctly, or the usual (ASME type ed. I986) techniques have to be set at a high level of sensitivity or cut off : 20 or even 10 % DAC. This sensitivity leads to many indications and also to false calls. Such defects are Lacks of Fusion (LF), Cracks (mechanical fatigue, thermal fatigue, corrosion, reheat, solidification, …). This whole group of defects, homogeneous only from an NDE point of view, are **referred to as PPD**. Such defects are considered here and in the other cases with a through wall size (DZ) larger than 5% of the wall thickness (T).

Volumetric defects are also considered but more often as examples as the detection and sizing performance of NDE procedures is often better with volumetric defects. This family of defects includes slag, inclusions of all kinds, pores, porosities, lack of penetration and certain lack of fusion (e.g. between two passes in a weld). This category of defects is **referred to as VTD**. Isolated defects of equivalent diameter less than 5 % of the wall thickness are generally not considered.

It is Important to stress that the present synthesis of NDE effectiveness does not consider diffuse defects such as Intergranular attack (IGA, not resulting in a crack), except in the case of steam generator tubes made of inconel.

3.3. Components

1. Welds in **heavy section pressure vessels of ferritic steel** (A533, 508, …), in flat plates of the same material type. Wall thickness (T) is generally more than 75 mm. (usually from 100 mm to 250 mm). Welds are of different kinds : MSAW, TIG, NGW, EBW, … . Defects considered are generally the PPD ones with isolated examples of VTDs.
2. Circumferential or longitudinal weld zones in **heavy section ferritic steel piping** (with internal ss cladding or not) of large diameter (D > 250 mm) or (considered as equivalent for NDE purposes) flat plates or pressure vessels made of carbon steel, where T is of the order of 50 mm (30 < T < 75).
3. Circumferential or longitudinal welds zones in **heavy section ferritic steel piping** (with internal ss cladding or not) of large diameter (D > 250 mm) or (considered as equivalent for NDE purposes) flat plates or pressure vessels made of ferritic steel where T is of the order of 15 mm (10 < T < 30).
4. Weld zones in **small diameter ferritic steel piping** with or without cladding. T is ranging from 5 mm to 30 mm. D is in between 50-250 mm.
5. Weld zones (including counter-bore area)in **wrought austenitic steel piping** (316, 304, … families) or in flat plates or pressure vessels with a wall thickness in all cases larger than 30mm. Piping diameter is larger than 250mm.
6. Weld zones in **small section piping, pressure vessel** or flat plate made of wrought austenitic steel. T < 30mm. D is in between 50-250 mm for the piping.
7. Weld zones, including counter-bore areas, **in thick section, large diameter piping made of cast austenitic steel** (statically cast or centrifugally cast ; piping or elbows). T > 30 mm, D > 250 mm (often, T is approximately 75 mm and D > 600 mm).
8. **Dissimilar metal weld zones, piping or components** made up of ferritic steel (cladded or not), buttering (inconel or other), and austenitic steel of the 316 type. T > 30 mm, D > 250 mm.
9. **Tubes** (welds or base metal) **made of austenitic steel** (inconel, incalloy, 316, …). 1 < T < 5 mm, D < 50 mm. Defects are of the PPD and GVD types with IGA.
10. **Tubes** (welds and base metal) **made of ferritic steel**. T < 5mm, D < 50 mm.
11. **Thin Plates** of high strength steels, alloys or simply of aluminum alloys, typical of the aeronautic industry : T < 5 mm. Defects are cracks e.g. between rivets.

12. Component 12 is representing a situation of free access to the **surface of a componen**t for the easy use of surface inspection techniques. Such inspections aim at the detection of surface breaking defects or of defects very near to the surface. Such surfaces can be the external or internal one of components of the above categories: 1, 2, 3, 4, 5, 6, 7 and 8 mainly.

3.4. Inspection procedures

a) **Standard industrial ultrasonic procedures** giving often acceptable results (e.g. ASME XI 1986 / 20 or 10 % DAC). Such procedures are based on simple techniques : 0, 45, 60 deg probes, contact, 2 to 5 MHz, complemented with 70 deg angle probes for near surface PPDs or with tandem if detection of embedded defects is required.
b) **Industrial ultrasonic procedures of low capability** level, unfortunately still common (e.g. ASME XI 1974,79 / 50 or 100 % DAC). Such procedures are based on low sensitivity (setting by calibration) techniques at 0, 45, 60 deg.
c) **Advanced ultrasonic procedures** which are generally based on techniques <u>adapted to the components and the defects</u> to detect and which work at high

sensitivity (noise level or 10 % DAC). Best examples are the ones of inspection procedures used for the ISI of nuclear components in Europe ; they combine standard techniques (0, 45, 60 deg probes) in contact or focusing in immersion , with more advanced techniques or transducers such as 70 deg. SE (emitter, receiver crystals separated in the same body), longitudinal waves, creeping waves, time of flight, phased arrays, reconstruction algorithms, …. Such effective procedures are involving both detection and sizing of defects.

d) **Procedures based on Eddy Currents** for tubing inspection. These procedures are based on ET and are called bobbin coil, rotating coil, pancake coils, phased arrays, …. These procedures are generally used for industrial inspection of heat exchangers. They sometimes combine ET with UT

e) **Radiographic procedures of industrial character** based on standard RT equipment (50, 150, 200, 320, 400, KV XRay tubes, 1MV, 2MV, 6MV, 8MV, .. linear accelerators, Co 60, Ir 20, gamma sources) or real time examination systems. Such procedures, as a minimum, follow the ASME standard and and use single wall techniques. Generally, Real Time Radiography can be included in this category, due to the sensitivity level. Procedures based on standard X-Ray equipment (e.g. microfocus), but with parameterisation in direction of examination are also included.

f) **Surface inspection procedures** based on techniques like Magnetic Particles (MT), Dye Penetrants (DT), and instrumented optical techniques used industrially (OT). In this category, other techniques were introduced by the offshore inspection: Ultrasonic Creeping Waves (UTCW), Alternate Current Field Measurement (ACFM) and Alternating current Potential Drop techniques (ACPD) for defect sizing.

Note. Techniques or procedures like laser interferometry, acoustic emission, thermography, neutron radiography, … also typically used to detect or locate defects in industrial components are not considered in the present evaluation of effectiveness.

3.5. Inspection levels

Inspections can be conducted at different “quality” or performance levels.
The present compilation considers three levels :

- **Q level** fixed by <u>Qualification</u> along the principle of the European Methodology which fixes the effectiveness of the inspection procedure, at a level considered possible after capability evaluation (e.g. RRTs). See 3.6.
- **B level** (<u>Blind</u> tests) corresponding to what was shown by 60% of the inspection procedures applied in RRTs relevant to the situation considered. Effectiveness can be very good with high performance inspection procedures and very low with low performance procedures even if applied with care by a good team.

3.6. Qualification of inspection procedures

The present report does not imply that inspection procedures used in industry must be qualified. But the detection performances, as well as the capabilities for defect sizing, classification and location are more difficult to quantify and to introduce into any structural evaluation scheme if the inspection procedures are not qualified.

Qualification (performance demonstration along the European Methodology) sets the performance level, considering the best possible performance that can be reached in industrial conditions by industrial inspection procedures.

In the presentation of results, the most important diagram given refers to inspection procedure results after qualification (Q). This should ideally happen in the future, for any application of NDE; qualification can be applied in different ways, depending on the situation, and at low cost, particularly if it is not refereed by an external authority (in house qualification or procedure proper evaluation).

3.7. Variables to be used for the quantification of NDE reliability

The essential variables used for the presentation of NDE performance (individual values or curves) are listed below.

FDP: detection performance of an inspection team or procedure for a given population of defects (also called FDF when comparing procedures)
CRP: correct rejection performance of defects to be rejected by the inspection procedure, along the ASME acceptance / rejection criteria (often around 10% of the wall thickness) ; (also called CRF when comparing procedures)
MESD/SESD: average error of sizing in depth standard deviation
MESL/SESL: average error of sizing in length standard deviation
MELS/SELS: average error on ligament size standard deviation
FCRP: false call rate leading to erroneous rejection.

Inverted diagram of detection and correct rejection use the following variables :

PM : probability of missing a defect of a determined population
PEA: probability of erroneously accepting a defect

The parameters used to illustrate the variation of detection and correct rejection performances are generally the defect length called “L” expressed in mm, and the defect size in depth called “D” expressed in mm or in % of the wall thickness, T.

Component, technique and application are coded on the diagram according to the codification scheme in appendix 3.

4. LIMITATIONS

4.1. Engineering type approach

As stated in the objectives, the present compilation and synthesis of NDE data provides trends, indications, orders of magnitude. It is not a strict statistical analysis. Several of the diagram shown are bench marks and are already used as input to structural integrity assessment schemes, but they derive from a digest of a large data base. This process inevitably entails some simplification of the data, to provide the broad statements of capability that are needed by manufacturers, users, integrity evaluators, regulators…

4.2. Presentation of results

It is not the intention of the study to present results in an exhaustive and precise manner. What is needed is an input for the consideration of NDE effectiveness and limitations in structural integrity schemes. Average values with confidence evaluations and trends are the only elements of information provided.

4.3. Confidence about the results and trend curves.

Detection

Values of variables like FDP (detection probability), or diagram representing FDP as a function of defect size are to be considered as average values (for each of the situations considered: component, material, defect family….) with rather large uncertainties. Most of the RRTs or exercises that generate such data deal with 10 to 40 defects in each cases; the average sample size is about 20 defects.

For sample sizes of 20 defects, the confidence limits at 95% on FDP correspond approximately to + and **-** 0.2. As advised by the NORDTEST group in its guidelines for replacing NDE techniques with another, the + / - 0.1 lower bound should always be considered a minimum uncertainty.

As an example, if a detection performance for planar flaws of 25 mm in the depth direction in a wall thickness of 200 mm is announced to be : FDP = .85, this value should be understood as being : $0.65 < FDP < 0.95$.
In the same way, declarations of performance equal to 1 could mean equal to 0.8 when based on RRTs or experiments.

In the case of qualified inspection procedures, the same precaution could have to be taken if the qualification trials consider limited numbers of defects for the verification of capability. Even if it is declared that all defects reaching the critical size or 50% of that size must be clearly detected, the limited sample size makes it necessary to consider the possible lower limit at 95% confidence) of 0.9. If the qualification relies on well established open trials and complete technical justification (as far as possible) then the blind trials are consolidated and the uncertainty is dramatically reduced (depending on the strength of the TJ).

Sizing

In the case of sizing, it is not always possible to indicate the standard deviation computed on the basis of the measurements. Often the error band has to be given as an evaluation based on experience or on very limited trials.

For usual metallic components with wall thickness ranging from 10 to 250 mm it has to be admitted that no industrially applied NDE technique, even the advanced ones, can claim for better precision than + / - 1mm in the depth and length. This small error band is however to be considered as the best possible result when no situations such as complex defects, segregation … are present. Blind trials statistics show standard deviations SES of about 3, 5 or even 10 mm.

4.4. Effect of particular parameters

The effect of several influential parameters is not considered in the compilation of capabilities hereunder except when part of a RRT. No systematic limit cases are considered such as combination of tilt and skew at the limit of what could happen in reality. Most of these parameters are listed and briefly discussed in chapter 9.

5. SUMMARY of the NDE EFFECTIVENESS DATA

5.1. Introduction

To give an idea of the NDE effectiveness it is necessary to condense the information into a few figures and data paragraphs. The best way to proceed is to consider only three groups of components. The validation of this extreme simplification is in fact provided by the detailed data themselves of this compilation.

5.2 Ferritic steel components

Figures of series 2 (in Appendix 1) are a good example of the variation in capabilities of UT and ET inspection. Figure 2.1 shows results expected from procedures qualified to the reasonably attainable targets for detection and sizing. Figure 2.2 pertains to 'good practice' procedures subjected to the qualification. Figure 2.3 shows what can happen due to poor (but still commonly applied) procedures, or due to environmental or human effects.
Key numbers are :

- Safe detection for defects of size in depth equal to 20 to 40 % T, for 'good practice' procedure.
- Safe or high sentencing of defects of sizes larger than 40 % T, for 'good practice' procedure.
- Average sizing error in depth MESD = 3 mm with SESD = 5 mm for qualified procedures, to MESD = -5 mm and SESD = 15 mm for weak procedures.
- Length sizing performance is illustrated in the same way : MESL = 3 mm and SESL = 10 mm, to MESL = -20 mm with SESL = 30 mm.
- Ligament sizing: MELS = 2.5 mm with SELS + 5 mm.

Defects shorter than 20 mm in length are less reliable detected with UT.

5.3. Austenitic steel piping weld area / Trimetallic weld

Figures of series 5 are less appropriate as, even for wrought material, welds are made of cast metal.
Bench marks are 40% T for acceptable sentencing capability for 'good practice' procedures. However, 100% success is never obtained.
Sizing data reveal difficulties :

- MESD = 0 mm with SESD = 5 mm, to MESD = -4 mm with SESD = 7 mm, but only for defects larger in depth than 50% T.
- MESL = -5 mm with SESL = 12 mm, to MESL = -10 mm with SESL = 40 mm, again only for deep defects.

Corrosion defects such as IGSCC's yield lower values.

5.4. Thin wall tubes or plates

Combining steam generator tubes, heat exchanger tubes, and thin metallic plates, NDE performance can be summarised by the diagram of series 9 relevant to ET. Bench mark numbers are again 40 % T or more to reach acceptable performance in defect sentencing.
Large dispersions exist for length sizing: SESL = 4 mm to 9 mm.

5.5. Surface Inspection

Performant detection is shown of surface breaking cracks in a situation suitable for surface inspection techniques application (MT, DT, ET, ACFM, UTCW, …).

Detection frequency of 100% was obtained, during several benchmarking exercises, for surface breaking cracks with depth larger than 5 mm.

Sizing appears to be effective for these surface breaking defects if the detection/sizing techniques are complemented with potential drop techniques (ACPD), easy to apply when the surface of interest is effectively accessible: average over-sizing (MESZ) of about 2.5 mm was found; the standard deviation (SESZ) is less than 2 mm.

Such results are valid only in good inspection condition.

5.6. Input data for integrity assessment models.

If a) inspection targets are clear and used to define targets or levels of qualification, and b) such targets are acceptable for some procedures (as shown by exercises or previous evaluations), and c) qualification can be performed with all the necessary elements to provide the operator with a procedure known for its capability (European Methodology), then it is easy to provide the structural integrity engineer with objective data of inspection capability (or effectiveness, if relating it to a specific application). This information is of the type given by figures 14.5.a and 14.6.a. It appears reasonable to declare that, if no defect that is deeper than 40% T is found by these high effectiveness inspection procedures then no such defect exists in the component.
Any kind of probabilistic input of the data for defects smaller than 40 % T is possible but probably of limited realism as no input data exist about the defect distribution in different components after fabrication and after service, before inspection. It seem unlikely, due to the cost on numerous metallurgical expertise necessary, to obtain one day such a complete information except in some particular cases such as the steam generator tubes.

For surface breaking defects that can be inspected by surface inspection techniques, the same reasoning could be followed with reference depth sizes of 5 to 10 mm.

6. REFERENCE DOCUMENTS CONSIDERED

Many reports were considered for the compilation of the NDE effectiveness data: most of them are given in the reference list. However, the ‘digest’ of data has been build up over 20 years by the JRC team in the framework of NDE reliability. Several aspects that have influenced the writing of this report are based on unwritten experience or knowledge that is difficult to extract from any one published report.

The major NDE programmes that were considered here are the three phases of PISC, including the parametric studies, the DDT exercise in UK, the PVRC / HSST programme results, the IGSCC training programme in USA, the available data on other performance demonstration programmes of EPRI, the IVC programme, the Nordtest programme (covering a very large spectrum of cases) and techniques including the Kochum programme, the NIL programme (up to 1996), several projects of JAPEIC, NRC / BATTELLE-PNL projects, TWI projects, DNV reports, VERITAS projects, NE-ME-TWI projects, ENEL projects, EDF-FRAMATOME-WESTINGHOUSE projects, VTT reports, UCL projects, some results of ICONE and of TIP, some projects of AMES in USA, ….

References to the reports of these programmes are generally not given in the text, in view of the process of compilation leading to a ‘digest’ of information.

7. VOLUMETRIC INSPECTION EFFECTIVENESS

7.1. Heavy section steel vessel (component 1)

a. Component description

Weld zones in heavy section pressure vessels of ferritic steel (A533, 508, …), in flat plates of the same material type. Wall thickness (T) is generally more than 75 mm. (usually from 100 to 250 mm). Welds are of different kinds : MSAW, TIG, NGW, EBW, … . Defects considered are generally the PPD ones with some isolated examples of VTDs.

b. Inspection effectiveness in general

The most relevant references to this category of components is the PISC programme. Several other programmes (e.g. PVRC, Framatome, DDT, Nordtest, ...), were conducted but either produced results of lesser statistical significance or generally confirmed or anticipated the PISC results.

From PISC, conclusions were drawn on the detection, location and sizing capability. Few attempts were made in PISC to classify the defects in the case of thick walled pressure vessels or plates made of ferritic steel.

It was concluded that inspection procedures based on ultrasonic as well as the ones based on X-Ray can meet the inspection objectives required by the safety assessments. Figure 1.1 illustrates this capability of detection and correct sentencing for the PPD family of defects when procedures are qualified to the best attainable level. For planar defects of 10% of the wall thickness, the expected detection rate is around 95%.

Sizing by ultrasonic procedures used after qualification, could lead to oversizing in depth (of 3 mm) but with a standard deviation SESD of 5 mm. Errors on the length measurement could be in ESL = 3 mm with SESL = 10 mm, after qualification

Certain conditions have to be satisfied, like the correct selection of techniques, correct access, and the necessary qualification programme.
Sizing of multiple defects remains difficult, mainly due to the lack of time or resources often dedicated to defect classification.

Challenging inspections were performed in penetrations of thick walled vessels, in inner radius corners of nozzles, … In all cases, qualification predetermines the effectiveness of the inspection.

c. Typical results of UT procedures for PPDs

Diagram 1.2. shows reference effectiveness values if no qualification programme is applied. This is for good inspection practice that would, with qualification, give performances of the order of the ones of figure 1.1.
Diagram 1.3. indicates how poor the performance can be, if poor NDE procedures are used or if the application and human factors are not controlled by qualification and the application of a quality assurance programme. These values could also correspond to lower bounds for manual inspection conducted in very difficult conditions or environment.

Sizing capabilities of type a and b procedures applied during PISC are illustrated on figure 1.4.

d. Typical results of RT procedures for PPDs

Very little data are available on the effectiveness of Radiographic techniques for PPD's. More exists for GVD's.
The PISC exercises conducted on pressure vessels and components of thickness greater than 150 mm gave results very similar to the ones of figure 1.1 ; obviously, depth sizing does not apply, for RT. It is however interesting to note that not the same defects are missed by UT and RT but, on the whole, the two techniques seem to complement one other. These results were generated during round robin testing (MINAC) and prior to destructive examination using a linear accelerator.
PISC results agree very well with the extensive study conducted by Magnox Electric, Nuclear Electric and TWI.
Real PPDs, even if highly tilted, present irregularities which make them detectable if deeper than 10% T. It is assumed that the tilt angles would not be much larger than that of the weld preparations (e.g. 30%).The effect of defect shape is not to be considered in thick sections : no planar defect is likely to have elongation less than 1 (PISC parametric studies).

Sizing in length of the defects using Radiography often demonstrated weaknesses, for natural planar defects due to limited detection of the extremities.
Typical values are, using PISC data : MESL = - 30 mm, SESL = 50 mm.

e. Volumetric defects.

For detection, Figure 1.5 is a typical diagram of PISC II. It is obtained in a very pragmatic manner but confirmed by several models, and shows the variation in detection performance with defects type, for ultrasonic procedures of the a/B type.
It appears that any volumetric defect of 1 or 2 mm equivalent diameter starts to be detected, and high detection performance is reached for defects smaller than 5 % T. These values are applicable to Radiography.
Qualification of the inspection procedures would select those capable of the best performances and detection of 1 % T defects would not be uncommon in the GVD category.

Sizing errors are, however, very different for radiography and ultrasonics.
Typical values extracted from the PISC programme are :

- Radiography : MES = - 2mm, SES = 5 mm (defect morphology is important)
- Ultrasonic : MES = +15 mm, SES = 30 mm

Sizing of small defects (and in particular of volumetric ones) with some standard ultrasonic techniques leads to the measurement of the beam width and not of the defect size !
Qualified procedures could obtain : MES = +5 mm, SES = 5 mm.

f. False calls

If the welds are made with full penetration and if the weld crowns are surfaced by grinding (generally the case), the false call rate in such components was always found to be very small or even not significant. Erroneous declarations were generally found to correspond to severe mispositioning of defects, by : up to 100 mm due to the large thickness and angle plotting errors.

7.2. Heavy section carbon steel piping (component 2)

a. Component description

Circumferential or longitudinal welds zones in **heavy section ferritic steel piping** (with internal ss cladding or not) of large diameter (D > 250 mm) or (considered as equivalent for NDE purposes) flat plates or pressure vessels made of ferritic steel. T is of the order of 50 mm (30 < T < 75).
Such components were inspected mainly in the PISC and TWI programmes.

b. Inspection effectiveness in general

The inspection procedures capabilities and effectiveness in general are very similar for pressure vessels walls and welds and for heavy section large diameter piping. Due to a reduced wall thickness compared to the thick walled vessels, and to the configuration of many welds suitable for simple mechanised scanning, detection and sizing performances can be somewhat better, particularly for the standard deviation of he sizing errors.

If qualification of the inspection procedure is accepted at a rather high level, as demonstrated during the PISC exercises, then figure 2.1 illustrates detection and sizing performances to be expected. Defects considered are mainly ones of the PPD family.

Industrial procedures well adapted to the situation would be able to size the depth of a defect with a dispersion characterised by a SESD = 5mm. Some procedures particularly adapted to and qualified for one family of defects could reach SESD values as small as 2mm during blind tests.

c. Typical results of UT based procedures for PPDs

Diagram 2.2. shows reference effectiveness values if no qualification programme is applied on ‘good practice’ inspection procedures.
Diagram 2.3. indicates how poor the performance can be if poor NDE procedures are used, or if the application and human factors are not controlled by a quality assurance programme. These values could also correspond to lower bounds for manual inspection conducted in very difficult conditions or environment (e.g. some off-shore situations).

The effect of defect length on detection is to be noted : defects of the PPD family shorter in length than 10 mm can be missed easily and can be very badly sized. The precise sizing performance depends on the type of UT technique (beam width).
Circular defects of 5mm diameter are much more difficult to detect than a 5mm deep and 20 mm long defect, as shown by the parametric studies of the PISC II programme.

d. Typical results of RT based procedures for PPDs

There are very little data on the effectiveness of Radiographic techniques for PPDs in PISC. NE/ ME/TWI exercises and the Kochum project (Nordtest), conducted on components of thickness greater than 30 mm, containing PPD defects, gave results similar to the ones of figure 2.2 ; obviously, the depth sizing data does not apply. It is interesting to note that Nordtest and NIL propose a ranking of defect correct rejection, for defect depth greater than 10 mm :
U20 > R5 = R4 = U50 > R3 = U100 > R2
where -U20 means sensitivity setting equal to 20 % of the echo from a 3 mm side drilled hole (U50 means sensitivity setting at 50 %, etc.).
-R2 means defect acceptance in radiography for IIW class 2.
CRP of R3 or 2 is proposed at about 0.8 (with lower bound at .5) for a 15 mm deep defect (i.e. about 30% T)

Real PPD defects, even if highly tilted present irregularities which make them detectable, in principle, if deeper than 10% T. It is assumed that the tilt angles would not be much larger than that of the weld preparations (e.g. 30 deg).
NIL and Nordtest show results of lower capability, probably due to human factors. It seems however possible to reach high effectiveness with RT procedures that would pass a stringent qualification programme, as shown by the NE / ME / TWI results.

The effect of defect length needs to be considered in these components, where defects of 15 mm in height can represent 20 to 50 % T sections. Several programmes indicate that detection performance reaches stable values for PPD’s longer than 3 to 5 mm. UT procedures show more sensitivity.

Sizing in length of the defects using Radiography often demonstrated weaknesses for natural planar defects due to limited detection of the extremities.
Typical values would be, interpolating between several sources of partial data :
MESL = - 10 mm, SESL = 30 mm.

e. Volumetric defects.

The typical PISC diagram of figure 1.5 is applicable. It appears that any volumetric defect of 1 or 2 mm equivalent diameter starts to be detected and high detection performance is reached for defects smaller than 5 % T. These values are applicable to Radiography.
Qualification of the inspection procedures would select those capable of the best performances and detection of 1 % T defects would be achievable in the GVD category.

Sizing errors are however very different for radiography and ultrasonic.
Typical values extracted from several programmes, are :

- Radiography : MES = - 1mm, SES = 5 mm (defect morphology is important)
- Qualified UT procedures could obtain : MES = +2 mm, SES = 5 mm.
- Ultrasonic type c procedure: MES = +5 mm, SES = 20 mm

Sizing of small defects (and in particular of volumetric ones) with some standard ultrasonic techniques often leads to the measurement of the beam width and not of the defect size !

f. False calls

If the welds are made with full penetration and if the welds, when made manually, do not exhibit the suck back phenomena (locally equivalent to a lack of penetration) the false call rate in such components is always found to be very small or even not significant. Erroneous declarations were generally found to correspond to severe mispositioning of defects by up to 50 mm due to the large thickness and angle plotting errors.

7.3. Heavy section ferritic steel piping / small thickness (component 3)

a. Component description

Circumferential or longitudinal welds zones in **heavy section ferritic steel piping** (with internal ss cladding or not) of large diameter (D > 250 mm) or (considered as equivalent for NDE purposes) flat plates or pressure vessels made of ferritic steel. T is of the order of 15 mm (10 < T < 30).

b. Inspection effectiveness in general

The discussion conducted for the piping with thick wall is also valid for wall thickness varying between 10 and 30 mm. Due to a reduced wall thickness compared to the previous component category detection and sizing performances of industrial procedures are often better, particularly in the standard deviations of the sizing errors.

If qualification of the inspection procedure is accepted at a high level, as demonstrated during several exercises, then figure 3.1. illustrates detection and sizing performances to be expected. Defects considered are mainly ones of the PPD family.

Industrial procedures well adapted to the situation would be able to size in depth with SESD = 3mm. Some procedures particularly adapted to and qualified for one family of defects could reach lower uncertainties e.g. SESD = 1 mm.

c. Typical results of UT based procedures for PPDs

Diagram 3.2 shows reference effectiveness values if no qualification programme is applied. Qualification can impose performances of the order of the ones of figure 3.1.
Diagram 3.3 indicates how poor the performance can be if poor NDE procedures are used, or if the application and human factors are not controlled by qualification and the application of a quality assurance programme. These values could also correspond to lower bounds for manual inspection conducted in very difficult conditions or environment (e.g. some off-shore situations).

d. Typical results of RT based procedures (single wall technique for PPDs)

NE/ ME/TWI exercises and the Nordtest project conducted on components of thickness < 30 mm, containing defects, gave results similar to the ones of figure 3.2 ; obviously, depth sizing data does not apply. The ranking of defect correct rejection (for defect depth greater than 5 mm) proposed by NIL is valid here as well (paragraph 7.2.d.)

Sizing in length of the defects using Radiography often demonstrated weaknesses for natural planar defects due to limited detection of the extremities.
Typical values would be, interpolating between several sources of partial data : MESL = - 5 mm, SESL = 20 mm.

e. Influence of the defect length (aspect ratio)

The effect of defect length needs to be considered in these components where defects of 3 mm in height can represent 10 to 30 % T. Several programmes indicate that detection performance reaches stable values for PPGs longer than 3 to 5 mm. UT procedures show more sensitivity : 20% T defects of the PPD family shorter in length elongation than 10 mm can be missed easily or can be very badly sized. The precise sizing performance depends on the type of UT technique (beam width). Circular defects of 5mm diameter could be much more difficult to detect than a 5mm deep and 20 mm long defect. Figure 3.4 illustrates this.

f. Volumetric defects.

The typical PISC diagram of figure 1.5 has limited applicability, since in reduced thickness components, ultrasonic techniques gain great benefit from the corner effect. It appears that any volumetric type defect of .5 or 1 mm equivalent diameter

starts to be detected and high detection performance is reached for defects smaller than 3 % T. These values are applicable to Radiography.
Qualification of the inspection procedures would select those capable of the best performances and detection of 1 % T defects would be achievable in the GVD category.

Sizing errors are very different for radiography and ultrasonic.
Typical values extracted from several programmes are:

- Radiography : MES = - 1mm, SES = 4 mm (defect morphology is important
- Qualified UT procedures could obtain : MES = +1 mm, SES = 2 mm.
- Ultrasonic type c procedure: MES = +2 mm, SES = 10 mm

Sizing of small defects (and in particular of volumetric ones) with some standard ultrasonic techniques often leads to the measurement of the beam with and not of the defect size !

g. False calls

If the welds are made with full penetration and if manual welds do not exhibit the suck back phenomena (locally equivalent to a lack of penetration), the false call rate in such components is always found to be very small or even not significant.

7.4. Small diameter carbon steel piping (component 4)

a. Component description

Weld zones in **small diameter ferritic steel piping** with or without cladding. T is ranging from 5 mm to 30 mm. 50 < D < 250 mm.

b. Inspection effectiveness in general

The discussion conducted for the small thickness piping is still valid for wall thickness as between 10 and 30 mm. However, an added complication is: the strong curvature of the component, which can be overcome using well adapted probes. For radiography, many situations will impede the use of single wall techniques. Radiography through the double wall thickness reduces very much the effectiveness of the procedures.
If qualification of the inspection procedure is accepted at a rather high level, as demonstrated during several exercises, then figure 4.1 illustrates detection and sizing performances to be expected as upper bounds. Defects considered are mainly ones of the PPD family. GVD family defects would give higher detection rates for small defects.

Industrial procedures well adapted to the situation would be able to size in depth with SESD = 3mm. Some procedures particularly adapted to and qualified for one family of defects could reach lower uncertainties e.g. SESD = 1 mm.

c. Typical results of UT based procedures for PPDs

Diagram 4.2 shows reference effectiveness values if no qualification programme is applied. Qualification can impose performances of the order of the ones of figure 4.1.
Diagram 4.3 indicates how poor the performance can be if poor NDE procedures are used or if the application and human factors are not controlled by qualification and the application of a quality assurance programme. These values could also correspond to lower bounds for manual inspection conducted in very difficult conditions or environment (e.g. some off-shore situations)

These results are valid only if the transducers are well adapted to the geometry of the component.

It is important to note that for welds difficult to inspect like nozzle welds in this type of piping, the FDF values can go down to 0.5 for defects between 10 and 40 % T (Nordtest).

d. Typical results of RT based procedures for PPDs

The Nordtest project conducted on components of thickness < 30 mm, containing PPD defects, gave results similar to the ones of figure 4.2 ; obviously, the depth sizing data do not apply to RT. The results apply only to single wall RT techniques.
Nordtest and NIL propose a ranking of defect detection for defect depth greater than 5 mm, as explained in 7.2 d.

Detection values for 5mm deep defects is FDP = 0.85.
Correct rejection values, for defects of 6mm are of the order of 0.6 (lower bound at 95% could be 0.2).
NIL and Nordtest show also results of lower capability, probably due to human factors. It seems however possible to reach high effectiveness with RT procedures that would pass a demanding qualification programme, as shown by the NE / ME / TWI results.

Sizing in length of the defects using Radiography often demonstrated weaknesses, for natural planar defects, due to limited detection of the extremities.
Typical values would be, interpolating between several sources of partial data :
MESL = - 5 mm, SESL = 20 mm.

e. Defect length (or aspect ratio) effect

The effect of defect length needs to be considered in these components where defects of 3 mm in height can represent 10 to 60 % T. Several programmes indicate that RT detection performance reaches stable values for PPDs longer than 3 to 5 mm.
UT procedures show more sensitivity : stable FDP is reached only for defect length greater than 10mm if the depth size is between 10 and 40 % T.
Defects of the PPD family, of depth 20% T, and shorter in length than 10 mm, can thus be missed easily or very badly sized. The precise sizing performance depends on the type of UT technique (beam width). Circular defects of 5mm diameter could

be much more difficult to detect than a 5mm deep and 20 mm long defect. Figure 4.4 is indicative for these components.

f. Volumetric defects.

The typical PISC diagram of figure 1.5 has limited applicability, since in reduced thickness components, ultrasonic techniques gain greater benefit from the corner effect. It appears that any volumetric type defect of .5 or 1 mm equivalent diameter starts to be detected and high detection performance is reached for defects smaller than 3 % T. These values are applicable to Radiography.
Qualification of the inspection procedures would select those capable of the best performances and detection of 1 % T defects would be achievable in the GVD category.

Sizing errors are very different for radiography and ultrasonics. Typical values extracted from several programmes are :

- Radiography : MES = - 2mm, SES = 5 mm (defect morphology is important)
- Qualified procedures could obtain : MES = +1 mm, SES = 2 mm.
- Ultrasonic type c procedure: MES = +3 mm, SES = 15 mm

Sizing of small defects (and, in particular, of volumetric ones) with some standard ultrasonic techniques leads to the measurement of the beam with and not of the defect size !
The present component geometry increases the scatter of results.

g. False calls

Missing information.

7.5. Wrought austenitic steel piping of large diameter and thick wall(component 5)

a. Component description

Weld zones (including counter-bore area) in **wrought austenitic steel piping** (316, 304, … families) or in flat plates or pressure vessels, with a wall thickness in all cases larger than 30mm. Piping diameter is larger than 250mm.

b. Qualified UT inspection results for PPDs

The starting point of the review is to identify a reasonably practicable level of qualification : the best attainable inspection capability of large diameter and thickness austenitic piping weld areas is then given by figure 5.1.
The weld texture in such components is typical of cast austenitic steels with long dendrites making ultrasonic wave propagation difficult to model and producing a

strong “ attenuation”. Sentencing of defects in the weld, or in the transition zone between the parent metal and the weld metal, is uncertain. The best capabilities shown during round robin testing do not allow any more severe targets for qualification than CRP = 0.95 even for 40 % through wall deep defects.

Sizing in depth is possible but with large uncertainties e.g. standard deviation SESD = 5mm even for a wall thickness of 30 mm and qualified procedures.
Length sizing also shows a lot of scatter: SESL of 12 mm.

The importance of false calls in such components when using non specifically qualified inspection procedures is to be noted. The correct use of several techniques and interpretation of their indications is the key for the reduction of false calls and depth sizing errors (e.g. mispositioning the crack tip in the weld metal)

c. Typical UT inspection results for PPDs

Good standard UT procedures, not submitted to qualification, performed in PISC and other RRTs as shown in figure 5.2. Even for through wall defects, sentencing in the weld area is difficult and CRF remains under .95. Sizing uncertainties are high e.g. length sizing is as follows, base on average results from several exercises: MESL = -10 mm ; SESL = 25 mm.

Several inspections not conducted with procedures well designed for the component and its material can give very low capability as shown in figure 5.3. representing probably a large part of the “inspection procedure population” still in use.

d. Typical RT inspection results for PPDs (Single wall techniques)

RT procedures are less sensitive to the type and texture of the materials. In cast austenitic steels (the weld metal in the present case) long dendrites aligned in the X-Ray beam direction give false calls.

Figure2.2 and the discussion of paragraph 7.2.d apply to the components considered here.

e. Corrosion and volumetric defects

These are considered in chapter 7.6, as little data is available for thick large diameter austenitic piping.

f. False Call rate.

There is insufficient data available to draw firm conclusions. The results shown in figure 6.6. for smaller diameter piping are probably a good indication of the possible false call rate; this, in turn, could lead to unnecessary repairs.

7.6. Wrought austenitic steel piping of small diameter and thick wall (component 6)

a. Description of the component

Weld zones in **small section piping, pressure vessel** or flat plate made of wrought austenitic steel. T < 30mm. 50<D<250mm for the piping.

b. Inspection effectiveness in general.

Several exercises and measurements apply to this component category. Training for IGSCC detection was generally performed on this type of component in the USA since the early 80's, and the PISC III programme made a comprehensive RRT on assemblies relevant to this component family, including inspection results from 23 teams (full procedure and individual technique results).
If the principle of qualification is accepted and applied to industrial inspections of high effectiveness, the results are given by figure 6.1, showing high effectiveness for defects larger in the depth direction than 40 % T.

For smaller PPDs, the sentencing uncertainty is significant, due to the texture of the weld metal which is a cast austenitic steel, unfavourable for UT inspection.

In the parent metal, when the ultrasound does not pass through the weld, the detection achieved in PISC exercise was equivalent to that obtained in the ferritic steel piping.

RT inspection has generally the same effectiveness as when applied on ferritic steel piping (chapter 7.3).

A differentiation has to be made not only between PPDs and GVDs but also between IGSCCs and the other PPDs. Corrosion defects are often more difficult to detect and very difficult to size. Sizing is characterised by large uncertainties due to the acoustic characteristics of the weld metal.

The importance of false calls in such components when using non specifically qualified inspection procedures is to be noted. The correct use of several techniques and interpretation of their indications is the key for the reduction of false calls and depth sizing errors (e.g. mispositioning the crack tip in the weld metal).

c. Typical effectiveness OF UT based procedures for PPDs

Figure 6.2 is based on an average of the best procedures evaluated in the PISC III exercise on this family of components. Sentencing capability does not reach 100 %, even for through wall defects. Uncertainties in sizing with these good practice procedures (not submitted to qualification) are high : SESD = 3 mm for a wall thickness of 12 to 22 mm.

Many procedures were less effective, as shown in figure 6.3. These results are indicative of the capability of procedures applied without qualification and not designed for the specific component.

d. Particular case of the IGSCCs

The effectiveness of UT inspection for IGSCCs alone is illustrated in figures 6.4 (qualified procedures) and 6.5 (‘ good practice’). Comparing these figures with figures 6.1 and 6.2 shows that the detection performance for IGSCC is poorer and that, even for 40 % T deep defects, the capability of sentencing is not 100 %.
Also, more systematic undersizing was found.
The PISC exercise highlighted variations in effectiveness even within the IGSCC family: complex IGSCCs and axial IGSCCs proved to be the more difficult to sentence.

e. Volumetric defects.

Such defects are generally present in the weld metal only. For this reason, due to the acoustic characteristics of the cast austenitic steel, such defects can be as difficult to size as the non-IGSCC PPDs. Figures 6.1, 6.2, and 6.3 are applicable. However sizing uncertainties in defect depth and particularly in defect length could be less than those given in figure 6.2 for the PPDs : PISC III gave some length sizing results of 5 < SESL < 10 mm.

f. RT based inspection procedures for PPDs

As stated already, the effectiveness data for the corresponding component made of ferritic steel is relevant here as well.
Paragraph 7.3 d is valid here and figure 3.2 is typical of the capability of single wall RT techniques when applied carefully.

g. Effect of defect aspect ratio

For ferritic steel components it was possible to discuss the effectiveness of detection and sizing as a function of the defect aspect ratio (shape). However, in the case of austenitic steel, there is inefficient data to enable such an analysis.

h. False call rate

For this category of component, false call rates were evaluated and their statistical significance. Several component areas, supposed to be free of defects, were inspected and then subjected to detailed destructive examination.
Figure 6.6 presents such results, globally stressing the false calls that would lead to rejection, to unnecessary evaluations and perhaps to unjustified repairs.

7.7. Cast Austenitic Steel Piping (component 7)

a. Description of the component

Weld zones, including counter-bore areas, **in thick section, large diameter piping made of cast austenitic steel** (statically cast or centrifugally cast ; piping or elbows). T > 30 mm, D > 250 mm (often, T = about 75 mm and D > 600 mm).

b. Inspection effectiveness with ultrasonic based procedures

Little data is available about the inspection of such components with techniques other than RT and visual inspection. The PISC III programme included a RRT using 3 welds in 31 inch diameter piping, with 10 teams inspecting them. The defects did not cover the whole spectrum that should be considered. They were representative ,to some extent, of PPDs but only 8 ones were available for NDE effectiveness evaluation after the destructive examination. Figures 7.1 and 7.2 should thus be considered as indicative only.
From these figures, is clear that no high target can be fixed for defect sentencing in such components. It seems possible to qualify procedures to a good detection standard but probably not for sizing characterisation.

False calls can be frequent as shown in figure 7.3.

c. Inspection effectiveness of RT based inspection procedures

As stated for the other stainless steel components, the RT capability is similar to that for that for the corresponding ferritic steel components, except that there is a higher false call rate, due to the dendritic structure of the cast / weld metal. In the present case, paragraph 7.2 d is applicable with figure 2.2; figure 7.3 indicates false calls recorded with RT techniques, but for detection only, i.e. it is not related to the repair programme for the component.

7.8. Dissimilar Metal Welds (component 8)

a. Component description

Dissimilar metal weld zones, piping or components, made up of ferritic steel (cladded or not), buttering (inconel or other austenitic “cast” steel), austenitic steel of the 316 type as weld metal, and wrought austenitic steel of the 316 / 304 types for the piping. T > 30 mm, D > 250 mm.

b. Effectiveness of inspection procedures in general

The component is generally a safe end area connecting ferritic piping with buttering to an austenitic (wrought or cast) piping.

This component is inspected in nuclear plant using ultrasonic (from the inside) and RT techniques (single wall). In the PISC exercise, an extensive RRT was conducted on four safe end components, with more than 20 teams.

The inspection effectiveness results are, in fact, very similar to the ones obtained for the austenitic steel piping and more particularly the wrought austenitic steel welded piping. Figures and discussions of the capabilities are thus the ones of chapter 7.6. The false calls were evaluated with care and the specific results are given in figure 8.1.
Using the large amount of data obtained, a diagram was drawn indicating how human factors can “modify” a defect population, when seen through the eyes of the ultrasonic procedures. Figure 8.2 shows how the defect sizes are erroneously shifted towards smaller values for the defects near to the rejectable size.

7.9. Austenitic Steel Thin Tubes (Heat Exchanger: component 9)

a. Component description

Tubes (welds or parent metal) **made of austenitic steel** (inconel, incalloy, 316, …). T < 5 mm, D < 50 mm. Defects are of the PPD type and of the GVD type with IGA.

b. Inspection effectiveness in general

Inspection of these tubes used as cladding and/or steam generator tubes is generally performed using Eddy Current based procedures. Several ultrasonic techniques are however applied when time and access permit. Under these circumstances, special RT equipment cab also be used, with high sensitivity and resolution (e.g. the micro-focus X-Ray equipment).
Industrial inspections are, however, largely based on ET. UT usually complement ET. In some cases, e.g. for cladding tubes, UT can be the main technique. Qualified procedure can achieve the effectiveness shown in figures 9.1 and 9.3, for PPDs and GVDs, respectively. This has been demonstrated by exercises like PISC and on site. Such results are for procedures combining the capabilities of various advanced ET techniques, and augmented by ultrasonic techniques.

c. Inspection effectiveness of inspection procedures based mainly on ET

Inspection of steam generators of nuclear reactors could give a very precise picture of the inspection effectiveness of ET techniques used in most procedures. However, destructive examination is rarely done or not fully detailed : pulling tubes out of steam generators and conducting metallurgical expertise is expensive. Data collected in USA, France and by PISC help to quantify the capabilities.

The most complete procedures, applied by trained teams which have complete information on the steam generator history, can be excellent (figures 9.1 and 9.3). However, figures 9.2 and 9.4 show a more typical level of effectiveness.

There is poor sentencing of cracks and volumetric defects. Also sizing in length and depth demonstrates large uncertainties : SESD = 0.3 mm for a wall thickness of about 1.2 mm and SESL = 9 mm for a critical crack length of about 13 mm.

It is generally only for defects reaching 50% of the wall thickness that sentencing capability reaches 80%.

d. Effectiveness of ultrasonic techniques

It would be misleading to believe that steam generator tubes can be inspected simply using ultrasonic techniques. However in some particular locations, ultrasonic techniques can be applied with high capability, but with a high risk of false calls. Some illustrative results are provided by the PISC exercise (RRT and certification of the defects) : figure 9.5 shows the detectability of crack like flaws using well adapted (qualified) ultrasonic techniques and gives an idea of the sizing capability in length that can be achieved by the best teams.

e. Effectiveness of RT techniques

If techniques like the micro focus examination are used, then detection of cracks and volumetric defects can be as high as or higher than shown in figure 9.1. For length sizing, even though crack extremities can be missed, the scatter of results is generally smaller than that obtained with ultrasonics and Eddy currents. Typical figures are MESL = -1 mm and SESL = 2 mm, as shown during the destructive examination of the PISC RRT assemblies.

f. Problem of the IGA type defects

Inter granular attack -typical of this type of component- is difficult to detect with any industrial or even advanced technique without producing an unacceptable rate of false calls. The sizing of the defective area is erratic

g. Welds in thin austenitic steel tubes

Weld inspection, e.g. cladding tube plug weld, present difficulties typical of those for cast austenitic steels. Good design of the weld preparation, small thickness and very specific techniques help to maintain good performance (e.g. figure 9.5). Corrosion is however difficult to detect.

7.10. Ferritic / High Strength Steel Tubes

a. Component description

Tubes (welds and parent metal) **made of carbon steel**. T < 5mm, D < 50 mm..

b. General effectiveness of the inspection

Very little information exists on the inspectability of this component. Information available at ENEL from a RRT by 6 teams, is summarised in Figure 10.1. It shows limit capabilities. Effectiveness reached by some procedures in the case of steam generator tubes of inconel could apply to the present case as well.

7.11. Thin Metallic Plates

a. Description of the component

Thin Plates of high strength steels, aluminium alloys, … , typical of the aeronautic industry : T < 5 mm. Defects are cracks e.g. between rivets or screw holes.

b. Effectiveness of the inspection

The aeronautic industry has made extensive studies of the NDE capabilities on such components. Figure 11.1 summarises the detection performance showing the effective detection of cracks of length 1 mm. Often the objective is the one of detecting only ! Sizing is thus not considered, as for other components. With particular ultrasonic waves (e.g. Rayleigh waves) at high frequency (e.g. 30 MHz), detection is even possible for defects of lengths 1mm and depth 0.1 mm. There is a high risk of f false calls. The uncertainty in sizing, shown by figure 9.5, applies here.

8. SURFACE INSPECTION TECHNIQUES

8.1. Bench-mark exercises results

The Visual inspection procedures considered are based on techniques like Magnetic Particles (MT), Dye Penetrants (DT), and instrumented optical techniques used industrially (OT).
Techniques or procedures like laser interferometry, acoustic emission, thermography, … also typically used to detect or locate defects in industrial components are not considered in the present evaluation of effectiveness.

Surface inspection with Eddy currents is also considered. It becomes more and more common in nuclear, off-shore and other industries.

Specialised ultrasonic techniques must also be included in the compilation: creeping waves.

Other electromagnetic type techniques were also successfully applied during bench-marking exercises such as the ACFM (Alternate Current Field Measurement)

Sizing in depth of surface breaking defects is effective with several techniques like TOFD, ET, ACFD complemented with potential drop techniques (ACPD).

The data is limited and mostly comes from the Nordtest, UCL, ICONE and TIP programmes (collaborative exercises aimed at off-shore structures inspection).
The compilation below will thus be completed in the future.

a. Effectiveness of MT and DT

The Nordtest, UCL and ICONE programmes gave the results shown in figure 12.1. Detection performance is good, even for relatively shallow flaws. If the defects are not as deep as 6mm, the length is a significant parameter, as shown in figure 12.2. Globally, for wall thickness ranging from 5 to 15 mm, it appears that 10 % wall thickness defects could be easily missed even if several mm long ! Setting more stringent targets is possible, as explained in the Nordtest programme, and qualification could thus assure better detection. This, however, remains to be done.

b. Effectiveness of Eddy Current techniques

ET effectiveness was evaluated in Section 7.9 (in a different context): figures 9.1, 9.2, 9.3, 9.4. are relevant to surface inspection, even though they represent a mixture of surface and near surface defects.
Figures 12.3 and 12.4 are resulting from different (underwater) inspection trials but conducted in ideal conditions.
Blind tests on offshore structures in real under-water inspection conditions demonstrate more variability.

c. Alternating Current Field Measurements (ACFM)

ACRM techniques were tested in the UCL and ICONE projects. The Results are showing a very similar good performance to that of other surface inspection techniques: figure 12.5 refers to cracks of the PDP family but surface breaking.

To be noted is that the ACFM technique was complemented with potential drop to obtain more consistent sizing results: for defects ranging from 3 to 10 mm in depth, the average sizing error (mainly over-sizing) is limited to MESZ = 2.5 mm and the average standard deviation is small: SESZ < 2 mm.

d. Ultrsasonic creeping wave techniques.

The creeping waves were also tested as part of the UCL and ICONE projects. Detection results are comparable to those obtained in 1984 in PISC II using the same techniques on heavy steel sections which surfaces were easily accessible. Figure 12.6. illustrates the detection performance as resulting from the UCL results.

8.2. Conclusion

The tests conducted under the NORDTEST, UCL and ICONE programmes show effective capability of defect detection if the surface is fully available for the application of surface inspection techniques

Such information results also from PISC II results: advanced sizing techniques (UTCW, ET, DT) applied on surface breaking cracks. The statistical samples were however judged small, by PISC, to draw final conclusions.

Tests on coated surfaces did not demonstrate important differences in ideal conditions of inspection. Trials were also made by the IVC.

Complex shapes of the components as well as more difficult (realistic) inspection conditions (under water real off-shore structure inspection) induce often losses of performance as shown by the ICONE programme results

9. INFLUENTIAL PARAMETERS

9.1. Effect of the defect characteristics

a. Correct classification of defects

The results of RRTs , for the classification of defects were generally not convincing. Good procedures follow a logical sequence: detection - classification - sizing ! This logic is not yet standard practice ! In some cases (e.g. steam generator tubes testing) procedures were able to identify cracks in 80 % of cases. For heavy section components, the use of specific techniques, on request, improved the differentiation between planar and volumetric flaws.

b. Defect characteristics

Several laboratory exercises were conducted to evaluate systematically the influence of defects variables like : class, surface roughness, aspect ratio, tilt and skew angles for planar cracks, position in depth,.. Figure 1.5 illustrates the importance of the parameter ‘family of defect’. Figure 13.1 is another example of extreme changes of response in amplitude of the same planar defect, as a function of the tilt and skew angles relative to the central plane of the weld. Such severe effects (e.g. amplitude reductions of 30 dB) necessitates qualification of the procedure.

9.2. Importance of the defect location

a. Ligament measurement

Obviously, the knowledge of the ligament size is essential to an integrity analysis. NDE techniques can size a ligament in the same way that they size a defect : by the detection and location of a crack tip. Ligament measurement capabilities are thus closely related to sizing capabilities.

In view of the simplification of the reported data, it is acceptable use that the values of SESD in Figures 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 5.1, 5.2, 6.1, 6.2, for ligament as well, e.g. standard deviation on ligament error SELS = 5 mm, for procedures qualified for thick wall pressure vessels.

If the defect is very near the surface, this uncertainty can be reduced by the use of specialised techniques. It can generally be assumed that the mean error MELS ~ MESD/2.

b. Through-wall position of the defect

The position in depth of the defect is a parameter used in several RRTs to present the results. It is an important factor for the performance of standard UT techniques: defects situated near the opposite surface to the scanning surface are often oversized due to the corner effect. In PISC it was shown that, with standard techniques, defects near to the scanning surface (clad surface in a pressure vessel) were systematically underestimated. Good practice and qualified procedures can overcome this effect.

9.3. Importance of the electronic equipment characteristics.

Within PISC II a parametric study was performed to evaluate the effect of a rather large number of variable parameters of the ultrasonic system : transducer electrical characteristics, cable parameters, ultrasonic equipment characteristics. Each of these parameters were made to vary individually and independently from the others. The effect of these variations on the defect detection performance and sizing performance were measured.

The study concluded that most of the effects are avoided or reduced by the technique calibration, if done properly. The only exception is when breakdowns or erroneous replacement of items occur (like cables of different lengths !). Variations measured, after calibration, in the amplitude of response as variable are generally less than 6 dB.

The aspect of electrical parameters is thus not considered in this report; it is assumed that the calibration and inter-changeability of components of the NDE system will be verified. It is however often not the case, e.g. calibration in the staff room with a short cable and measurements on the installation with a long cable !

9.4. Importance of the cladding of ferritic steel pressure vessels and piping

The cladding effects were measured in PISC II. The importance of these effects depends on the type of cladding and on the NDE techniques used.

Radiographic techniques generally suffer from the variation of thickness of the cladding between two strips or two wire passes. This affects the interpretation of the radiograms.

Eddy current techniques are affected as well, but the effects are not quantified.

Ultrasonic techniques can also suffer, due to the complex structure / texture of cladding strips or wires and heat affected zones. The back-wall echo, used as a measure of the attenuation, has shown in some cases of poorly selected transducer frequencies, up to 30 dB drop where the passes have been overlaid. Figure 13.2, illustrates this. Such local variations have to be considered in qualification plans. Beam distortions also introduce extra sizing errors, as shown in figure 13.2.b.

9.5. Note on very tight defects

If defects are very tight with contacts between the faces, UT waves could propagate through the defect and RT has no chance to see any reduction of metal path ! It is therefore prudent to accompany any inspection with an assessment or measurement of the possible residual stresses creating compressive stresses in the critical zones.

Several studies evaluate the effect of compressive stresses on the response of planar defects to ultrasonic testing. Few of these studies are comprehensive. Diagram 13.3 and 13.4 taken from a well organised and complete study in Japan show that the loss of amplitude of response can be more than 20 dB, even when using 5 MHz probes.

9.6. Importance of human factors

Action 7 of PISC analysed some human factors which influence the inspection results. Conclusions were detailed in specific reports. We note some results of importance for the organisation of a RRT.

Manual inspectors show considerable variability, depending on environment, motivation, etc. This variability can reduce the effectiveness down to 30%, and has cycles characterised by periods, e.g. a shift period (morning to evening), a week Monday to Tuesday), the learning time, high effectiveness periods; sometimes, demotivation also characterised the behaviour. Such effects can transform the performances illustrated on figure 1.2 down to what is shown in figure 1.3 !

The human errors were encountered at different stages of the inspection process: during calibration, during scanning, by mis-observation of the screen, during evaluation (simple computation), etc.

Besides these observations, the importance of human factors was noted in several exercises, either because of identified errors or during the discussions with teams about the effective application of their procedure. These observations suggest that similar events can happen in the reality of industrial inspections. Examples are as follows :

- Often teams make mistakes while installing their mechanised scanners on the assemblies, by misreading references or mis-coding parameters (clockwise or counter-clockwise).
- In several cases the scanners selected or the technique applied are not suitable for the extent in depth or in length of the flawed area. Non-detection or severe under-sizing happens due to this bad choice and not due to lack of capability of the technique.
- manual inspection influences defect sizing and defect classification due to direct intervention by the operator, e.g. very large flaws are hard to believe.

10. DEFECTS PRESENT IN THE COMPONENT / WELD AFTER INSPECTION

10.1. Chances of missing an unacceptable defect

From figures 1.1 and 1.2, it is possible to imagine a curve indicating the chances of missing a defect (of the PPD population used for the detection exercises). If qualification applies, figure 14.1.a. would be the example for pressure vessels. If the inspection procedure is standard but of good practice without qualification, the diagram becomes the one of figure 14.1.b.
Figures 14.1 also shows the defect size in depth which leads to very safe detection, in the case of correctly qualified inspection procedure.

10.2. Chances of accepting unacceptable defect (e.g. 10 % T deep defect or more).

The chances of accepting an unacceptable defect (e.g. 10 % T deep defect) corresponds to the chances either of missing such a defect or of badly undersizing detected defect larger than the acceptable limit size in depth. Figures 1.1 and 1.2 lead to figures 14.2. Here again the correctly qualified procedure shows an asymptotic values of defect size above which chances of erroneous acceptance are very low.

10.3. Presence of defects in a thick wall vessel component

a. After fabrication

After fabrication, the component contains fabrication defects. Statistics were established in PISC and by CEA / Framatome / JRC about the presence of such defects.
Destructive examination of the PISC assemblies revealed the presence of non-intentional natural defects of various kinds and sizes in depth.
On a total of more than 15 m of weld a diagram was established, as sown in figure 14.3, valid only for vessel welds. These small defects are of little structural interest.

b. During / after service

Only feedback from plant operation would yield such information. The information is not generally available : statistics for failures exist but data on defects which did not lead to failure are also needed.
Such information would have to be gathered from the ‘translation’ of all the indications recorded during ISI, if available from the plant operator. Such ‘translation’ would mean meters of weld to examine destructively with metallurgical expertise for each type of components, for each family of in service defects, etc.
The only solution is to consider the possible damages that can occur during service and to postulate that they will lead to a defects with a hypothetical repartition in size to be based for example on some information resulting from inspection and operation. Figure 14.4 is an example.

10.4. Presence of defects after inspection of a thick walled vessel

Using the information available in figures 10.1, 10.2, and 10.3, it is possible to imagine a curve corresponding to what could be left in a welded component (vessel type) after inspection. Figure 14.5.b corresponds to inspections based on usual good practices but without qualification. Good qualification would lead to the results shown on figure 14.5.a. If the curve in figure 14.2.a can be accepted with very tight confidence margin (based on a perfect qualification with compelling technical justification for full detection of rejectable defects), then, even without knowing precisely which defects of the PPD family could have been induced by service, it is clear that practically no defect larger than 40% T will ever be present in the component, if inspected regularly with a qualified procedure.

10.5. Presence of defects in large diameter piping

Destructive examination of PISC piping revealed a distribution of defects similar to that found in vessel welds, but with more cracks and lack of fusion in the range 3 to 10 % T.

The presence of defects in a large diameter piping weld could thus be as shown in figure 14.6.a. after a well qualified inspection. Clearly, if the qualification is mainly effective, the inspection makes almost unnecessary to know of the defect distribution before inspection.

If a confidence interval or lower bound has to be accepted on the qualified inspection results, then a difficulty remains even with these qualified procedures. Therefore the technical justification and open trials are important : 40 % T defects (as an example) must be detected with high confidence. Simply blind trials on 20 or 30 defects do not in themselves, demonstrate sufficient confidence for safety critical applications.

10.6. Presence of surface breaking cracks after surface inspection

Surface breaking defects deeper than 5 to 10 mm, if long enough (e.g. longer than 50 mm) appear to be safely detected with specialised techniques.

The 5mm defect could be considered as the cut-off size in the same way as the 40% deep defect is considered for the volumetric inspections, when using good practice inspection procedures, in good conditions, possibly after qualification.

11. INPUTS TO STRUCTURAL INTEGRITY ASSESSMENT SCHEMES

11.1. Origin of NDE data

NDE data generally results from the application of an inspection procedure based on several techniques, on the skill of the operator, on decision steps such as recording or not, geometric indication or not, false call or not, … The size of a recorded defect is usually established by the operator, often not following rigorous reasoning that could be documented. Even if, for reasons of qualification and credibility, the trend is to make inspection procedures, the NDE data used by the structural integrity engineer will always be the result of a complex combination of various information and decisions taken during the process of generating the information.

NDE data to be used are thus not usually simple output signals that can be correlated to a characteristic of the defect, but are declarations resulting from a complex diagnosis by an expert: a diagnostic.

11.2. Interfacing NDE diagnostics with Integrity assessment

Due to the complex characteristics of the NDE information generated by inspection, it is thus generally impossible to present this information as a simple “signal” distribution.

Without neglecting the value of several proposals for the probabilistic consideration of the information in integrity models, the most direct interfacing is by the quantification of the inspection reliability during qualification; the targets of the highly effective qualification represent the minimum performance.
Figure 14.5.a, for example, can be used if no defect larger than 40 % T was found ; it essentially means that no defect larger than 40% T is present !

If the qualification process is not supported (e.g. by a TJ or open trials) a confidence limit will have to be accepted for the probability of correct rejection. The result is that the integrity engineer will need to address the probability of operating with a 100 % T defect ! The situation is thus essentially the same as with no qualification, if the qualification is not performed correctly along the European Methodology to reach the quasi-certainty of detecting large defects. For defects smaller than the limit given as ‘critical’, after good qualification (e.g. 40%T or 5mm for surface breaking cracks) a probability of defect presence can only be established by using a postulated defect distribution before inspection (fabrication and service defects).

11.3. Conclusions

A simple input from inspection to be proposed to the analyst is possible to be elaborated only if the inspection procedure is effectively qualified to a good standard which allows to QUANTIFY what is the detection / sentencing capability of the inspection and which allows to state that defects above a certain size (safety objective) are safely detected and sized.

Any other type of inspection leads to excessive uncertainties and makes it impossible to quantify the distribution of fabrication and service defects left after inspection. Such (apparently) cheaper inspection could thus be considered as of marginal contribution to structural integrity. It could even induce the structural integrity assessment into error by giving the wrong impression that important defects are safely detected and thus not present in the component.

12. CONCLUSIONS

The NDE based inspection procedure often produces data of interest for structural integrity assessment.

This compilation exhibits that the information on inspection effectiveness is available for many situations. This information is digested for an easy understanding and use, as an input, for structural integrity assessment.

Qualified information is possible only if the inspection is conducted after an effective qualification programme, which ascertains the matching of the inspection targets.

However, Structural Integrity engineers must demand for reasonable TARGETS (e.g. , for stainless steel piping , fully safe defect detection and sentencing of 40% T - instead of 10%T).

In the compilation, data on defect missing probability are reported together with data on the probability of accepting those defects that should be rejected along standard acceptance criteria. Sizing errors, average and expected dispersions, are also reported. These errors are usually independent of the defect size.

This information can be translated into probabilities of defect presence in welded components after inspection, with condition of qualification of inspection.

Risk and problem areas that can not be managed without having a clear description of the situation (i.e. effect of cladding, residual stress ..) are identified.

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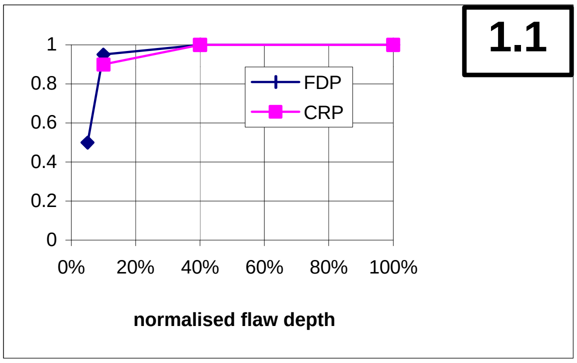
Appendix 1: All figures

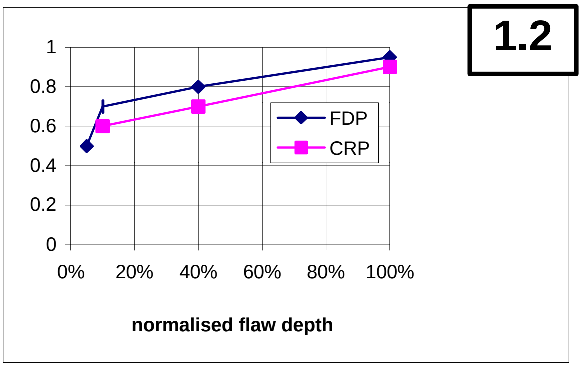
a1Q	5%	10%	40%	100%
FDP	0.5	0.95	1	1
CRP		0.9	1	1
MESD (mm)			3	
SESD (mm)			5	
MESL (mm)			3	
SESL (mm)			10	
FCRP			0.1	

1.1



a1B	5%	10%	40%	100%
FDP	0.5	0.7	0.8	0.95
CRP		0.6	0.7	0.9
MESD (mm)			5	
SESD (mm)			20	
MESL (mm)			5	
SESL (mm)			50	
FCRP			0.1	

1.2



b1B	5%	10%	40%	100%
FDP	0	0.1	0.25	0.4
CRP		0	0.07	0.1
MESD (mm)			-7	
SESD (mm)			15	
MESL (mm)			-30	
SESL (mm)			50	
FCRP			0	

1.3

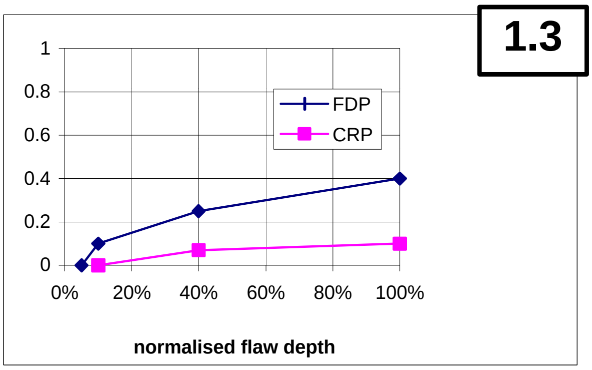


Figure 1: Inspection effectiveness for UT of pressure vessel with thick walls. Qualified procedure (a1Q), good practice (a1B), and low capability (b1B).

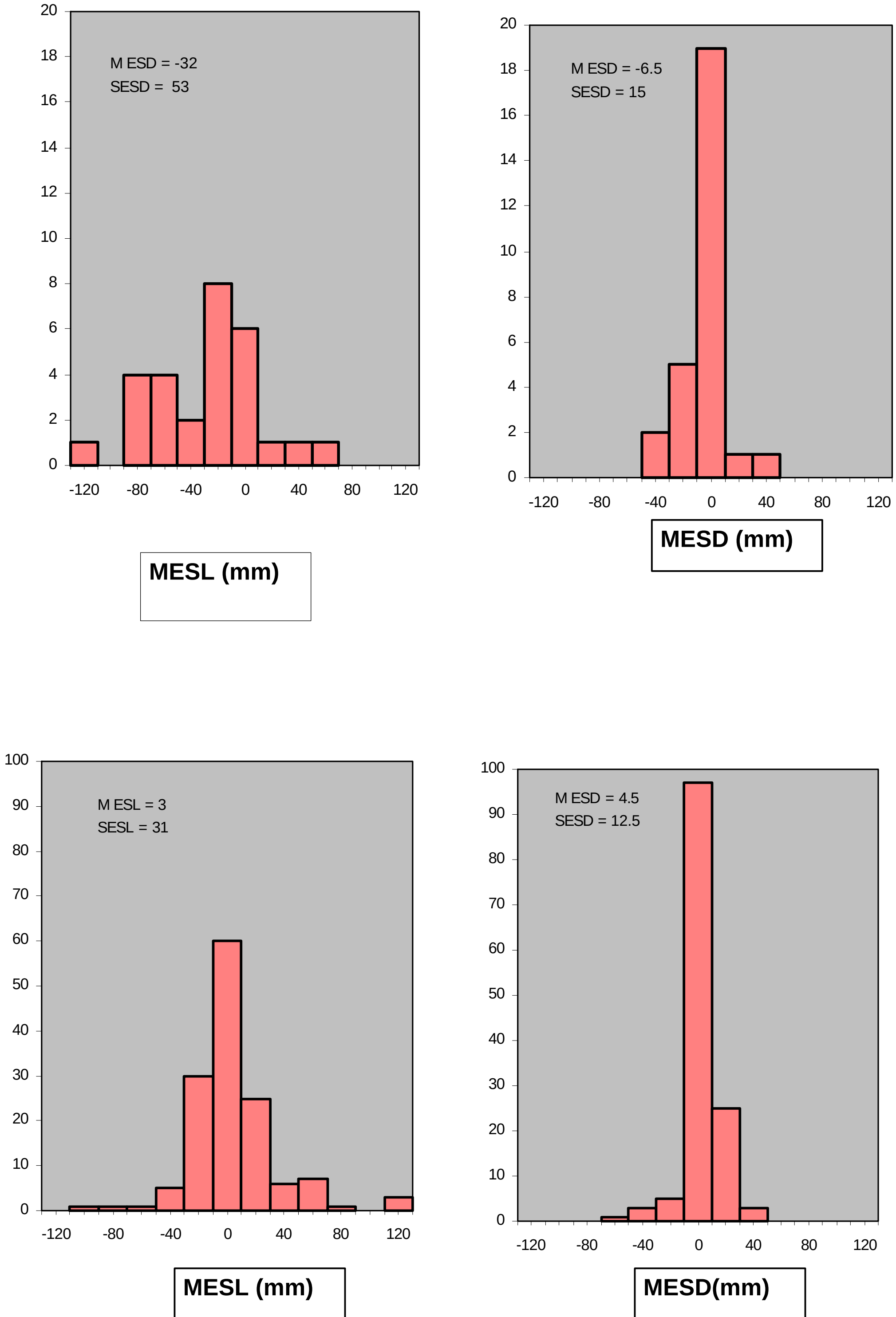


Figure 1.4: Distri rs on size in depth and btained during PISC II on plate nr. 3 using procedures of the b type (low effectiveness) and a type (good practice)

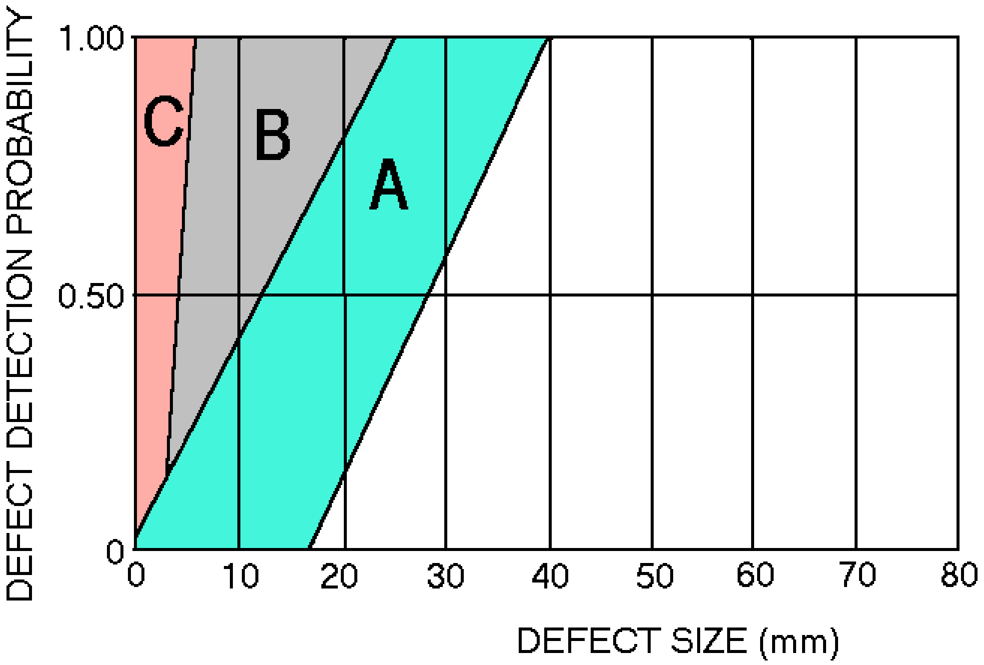


Figure 1.5: Detection probability of ASME-type procedures with recording level at 20% DAC as a function of the defect through wall size for the three categories of defects. **A)**: smooth, planar for ultrasonic wave length, sharp crack edges; **B):** hybrid defects or rough defects like hot tears; **C):** volumetric defects.

Team	Procedure	Scanning	Side	Sizing
DQ	Computer aided	manual with position encoder	inside	-6dB or half width of echo size
EN	X-rays (MINAC)	not applicable	inside	-
FM	Computed aided reconstruction algorithm: SAFT	automatic and manual	both	SAFT
HP	Pulse-echo/Tandem SAFT	automatic	both	SAFT and dB drop function of defect type - Tip location
IJ	TOFD	manual with position encoder	both	TOFD and SAFT
I	Focusing probes	automatic	inside	1) Tip diffraction 2) dB drop
LG	Ultrasonic holography	automatic	outside	holographic reconstruction
MF	EMAT	automatic	outside	SAFT and 50% DAC
QZ	Complemented ASME Section XI	automatic	outside	1) Tip diffraction if tip detected 2) -6db for focus probes 3) -6db for stand probes
RY1	Pulse Echo + TOFD	automatic	outside	TOFD and SEL probes Human expert
RY2	Pulse Echo + TOFD	automatic	inside	TOFD and SEL probes Human expert

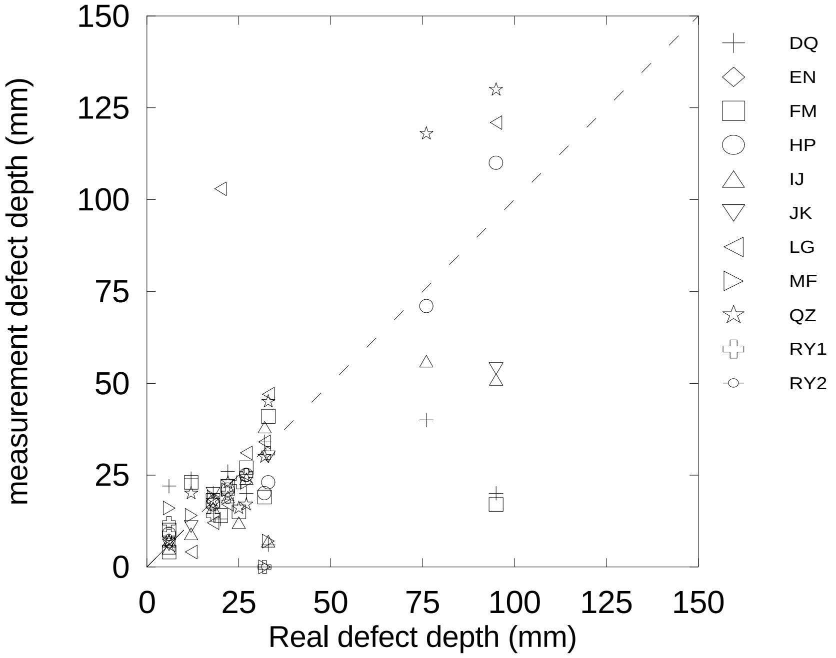
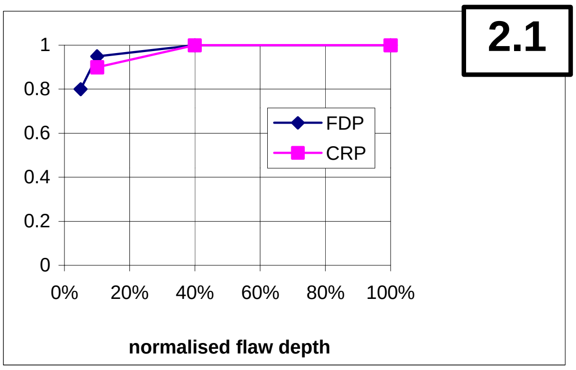


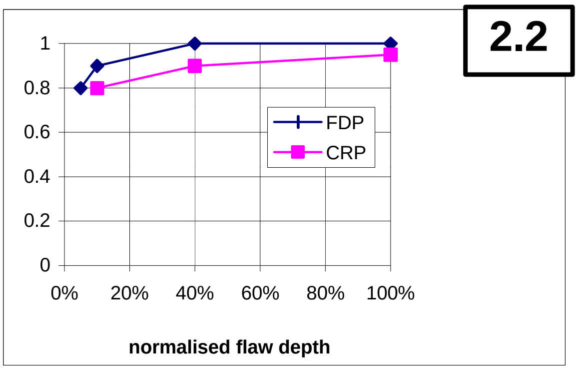
Figure 1.6: Sizing of defects in the full scale nuclear pressure vessel of MPA Stuttgart. PDP type flaws are generally well sized. Complex situation: PDP with GVD results in a random sizing. (PISC III report No. 26 - Action 2 -Phase 1, EUR 15371 EN))

a2Q	5%	10%	40%	100%
FDP	0.8	0.95	1	1
CRP		0.9	1	1
MESD (mm)			3	
SESD (mm)			5	
MESL (mm)			3	
SESL (mm)			10	
FCRP			0.1	



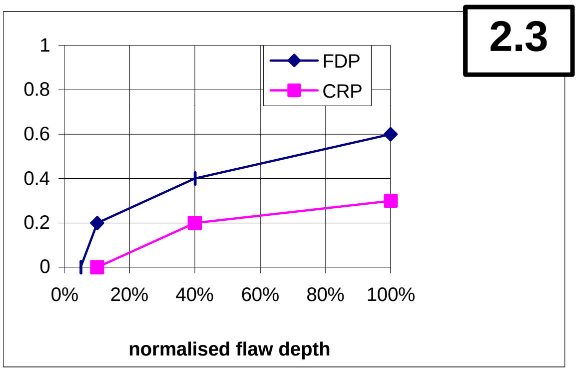
2.1

a2B	5%	10%	40%	100%
FDP	0.8	0.9	1	1
CRP		0.8	0.9	0.95
MESD (mm)			5	
SESD (mm)			15	
MESL (mm)			5	
SESL (mm)			20	
FCRP			0	



2.2

b2B	5%	10%	40%	100%
FDP	0	0.2	0.4	0.6
CRP		0	0.2	0.3
MESD (mm)			-5	
SESD (mm)			15	
MESL (mm)			-20	
SESL (mm)			30	
FCRP			0.2	

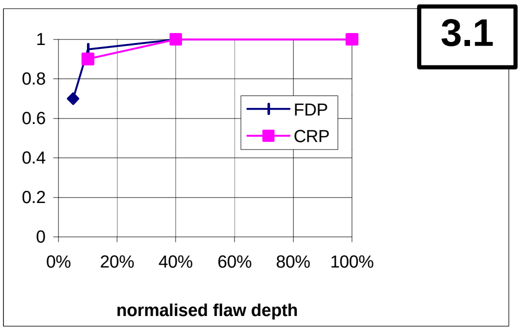


2.3

Figure 2: Inspection effectiveness for UT of large diameter and thick wall ferritic steel piping. Qualified procedure (a2Q), good practice (a2B), and low capability (b2B),

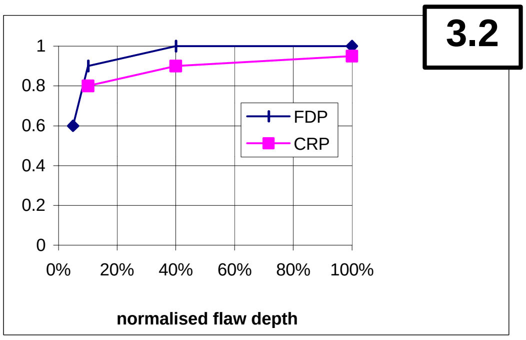
a3Q	5%	10%	40%	100%
FDP	0.7	0.95	1	1
CRP		0.9	1	1
MESD (mm)			1	
SESD (mm)			3	
MESL (mm)			2	
SESL (mm)			5	
FCRP			0.1	

3.1



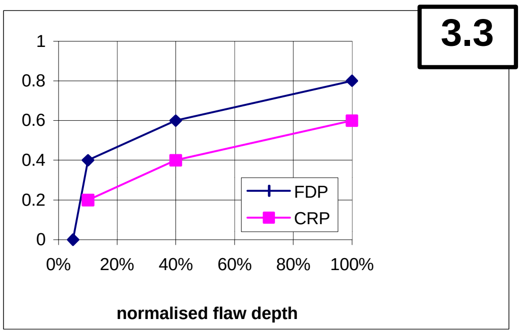
a3B	5%	10%	40%	100%
FDP	0.6	0.9	1	1
CRP		0.8	0.9	0.95
MESD (mm)			3	
SESD (mm)			5	
MESL (mm)			5	
SESL (mm)			10	
FCRP			0.1	

3.2



b3B	5%	10%	40%	100%
FDP	0	0.4	0.6	0.8
CRP		0.2	0.4	0.6
MESD (mm)			-3	
SESD (mm)			10	
MESL (mm)			-5	
SESL (mm)			20	
FCRP			0	

3.3



3.4

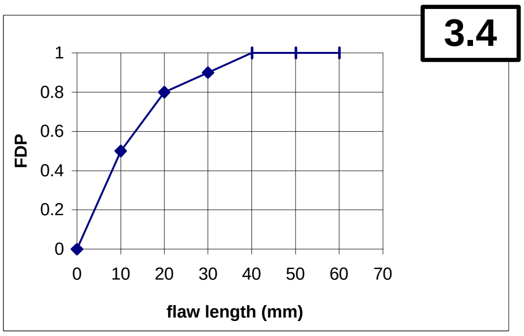
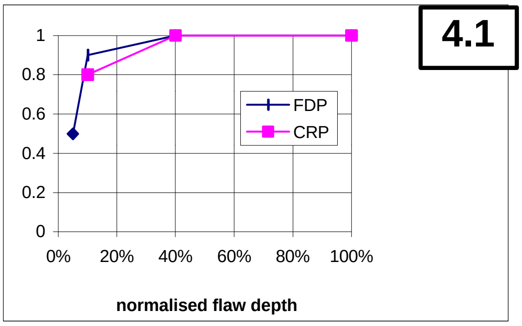


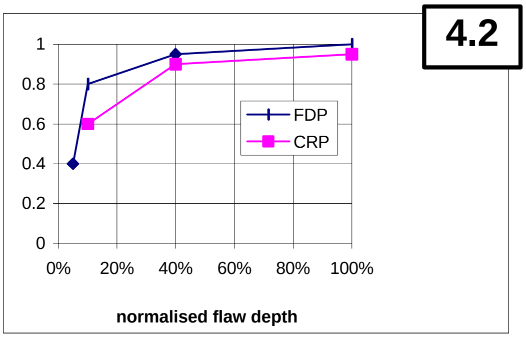
Figure 3: Inspection effectiveness for UT of large diameter piping with wall thickness less than 30 mm. Qualified procedure (a3Q), good practice (a3B), and low capability (b3B). 3.4 refers to the defect length (good practice a3B)

a4Q	5%	10%	40%	100%
FDP	0.5	0.9	1	1
CRP		0.8	1	1
MESD (mm)			2	
SESD (mm)			3	
MESL (mm)			5	
SESL (mm)			10	
FCRP			0.2	



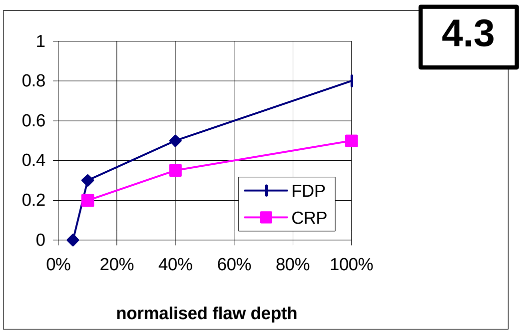
4.1

a4B	5%	10%	40%	100%
FDP	0.4	0.8	0.95	1
CRP		0.6	0.9	0.95
MESD (mm)			3	
SESD (mm)			5	
MESL (mm)			5	
SESL (mm)			10	
FCRP			0.2	

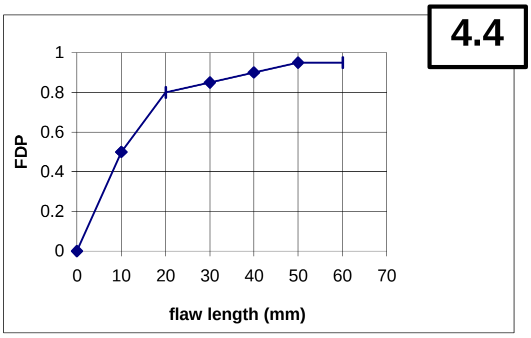


4.2

b4B	5%	10%	40%	100%
FDP	0	0.3	0.5	0.8
CRP		0.2	0.35	0.5
MESD (mm)			-3	
SESD (mm)			10	
MESL (mm)			-5	
SESL (mm)			15	
FCRP			0.1	



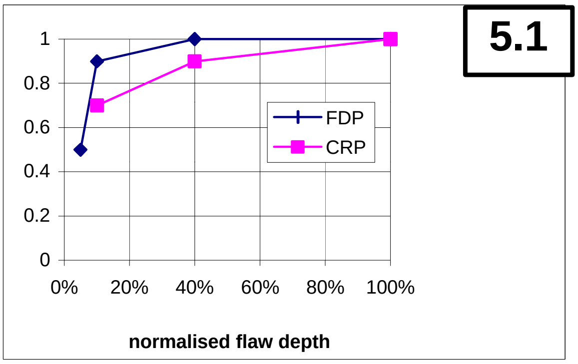
4.3



4.4

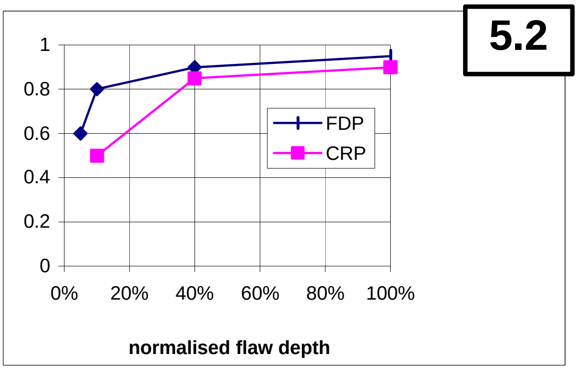
Figure 4: Inspection effectiveness for UT of small ferritic steel piping. Qualified procedure (a4Q), good practice (a4B), and low capability (b4B). 4.4 refers to the defect length (good practice a4B)

a5Q	5%	10%	40%	100%
FDP	0.5	0.9	1	1
CRP		0.7	0.9	1
MESD (mm)			0	
SESD (mm)			5	
MESL (mm)			-5	
SESL (mm)			12	
FCRP			0.05	



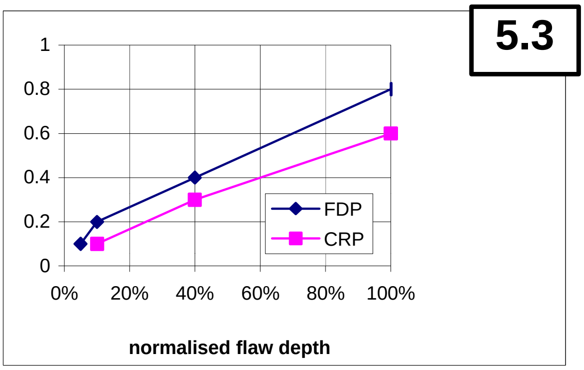
5.1

a5B	5%	10%	40%	100%
FDP	0.6	0.8	0.9	0.95
CRP		0.5	0.85	0.9
MESD (mm)			-2	
SESD (mm)			5	
MESL (mm)			-10	
SESL (mm)			25	
FCRP			0.25	



5.2

b5B	5%	10%	40%	100%
FDP	0.1	0.2	0.4	0.8
CRP		0.1	0.3	0.6
MESD (mm)			-4	
SESD (mm)			7	
MESL (mm)			-10	
SESL (mm)			40	
FCRP			0	



5.3

Figure 5: Inspection effectiveness for UT of large diameter wrought austenitic steel piping. Qualified procedure (a5Q), good practice (a5B), and low capability (b5B).

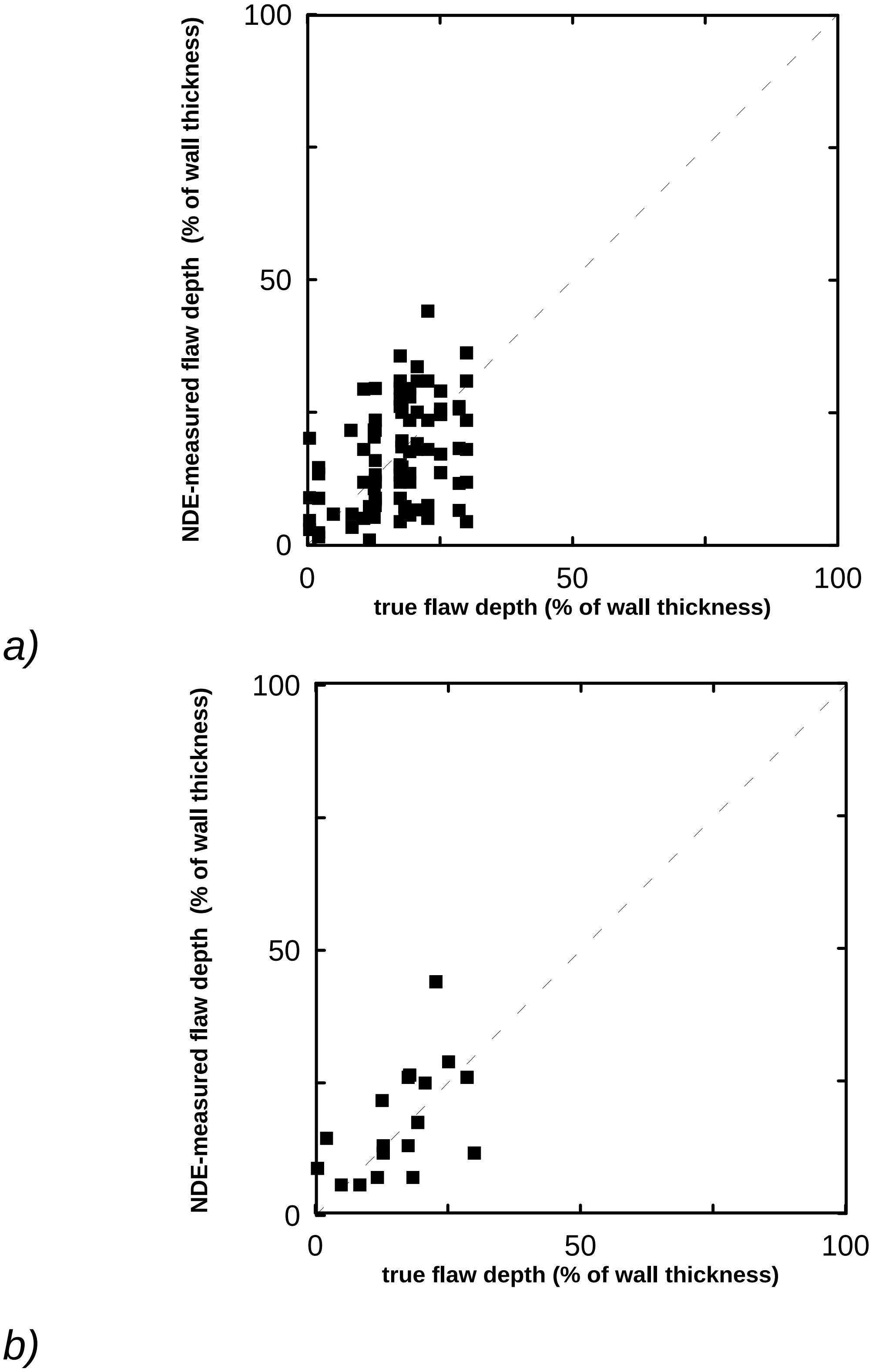
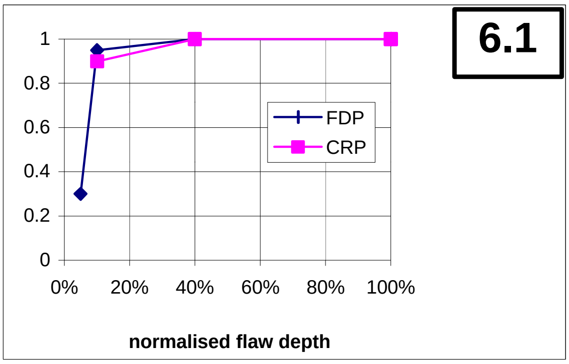
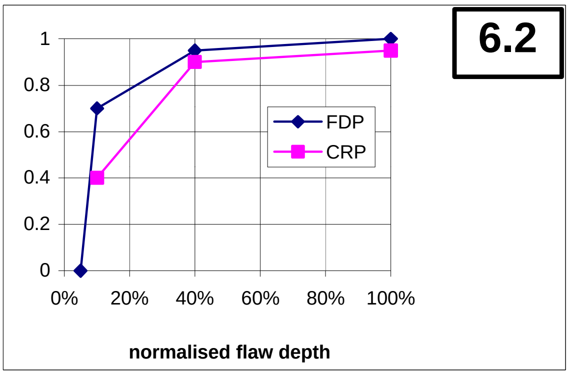


Figure 5.4: Wrought austenitic, diameter 31 inch, thickness 75 mm. Typical sizing dispersion for inspection procedures involving different techniques: standard pulse-echo, twin-crystal probes, focusing probes, SAFT-TOFD, EMATS, X-rays. a) All teams; b) one team that performed well (PISC III report no. 34, Action 4, EUR 15664 EN).

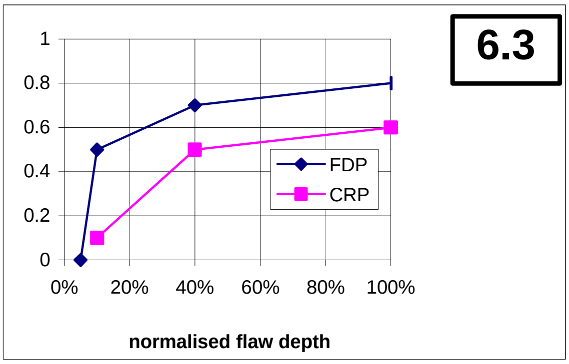
a6Q	5%	10%	40%	100%
FDP	0.3	0.95	1	1
CRP		0.9	1	1
MESD (mm)			0	
SESD (mm)			2	
MESL (mm)			-3	
SESL (mm)			10	
FCRP			0.05	



a6B	5%	10%	40%	100%
FDP	0	0.7	0.95	1
CRP		0.4	0.9	0.95
MESD (mm)			-1.5	
SESD (mm)			3	
MESL (mm)			-10	
SESL (mm)			25	
FCRP			0.2	

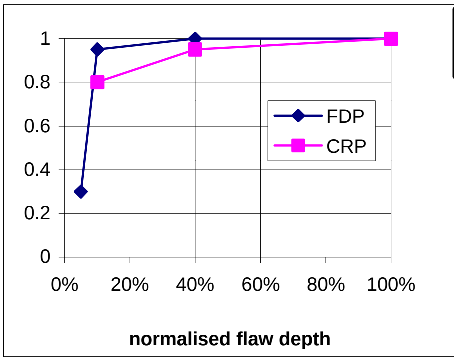


b6B	5%	10%	40%	100%
FDP	0	0.5	0.7	0.8
CRP		0.1	0.5	0.6
MESD (mm)			-4	
SESD (mm)			5	
MESL (mm)			-20	
SESL (mm)			20	
FCRP			0.3	



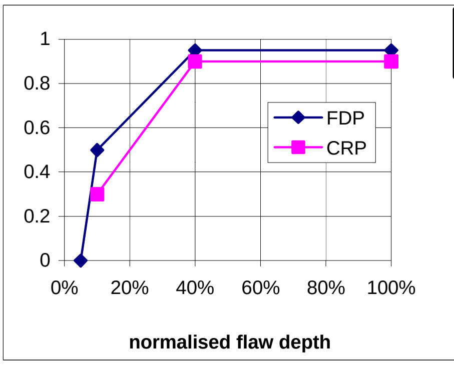
Figures 6.1-2: Inspection effectiveness for UT of small diameter wrought austenitic steel piping. Qualified procedure (a6Q), good practice (a6B), and low capability (b6B).

a6Q	5%	10%	40%	100%
FDP	0.3	0.95	1	1
CRP		0.8	0.95	1
MESD (mm)			-1	
SESD (mm)			2	
MESL (mm)			-5	
SESL (mm)			10	
FCRP			0.05	



6.4

a6B	5%	10%	40%	100%
FDP	0	0.5	0.95	0.95
CRP		0.3	0.9	0.9
MESD (mm)			-2	
SESD (mm)			3	
MESL (mm)			-20	
SESL (mm)			25	
FCRP			0.2	



6.5

Figures 6.4-5: Inspection effectiveness for UT of small diameter wrought austenitic steel piping for IGSCCs only

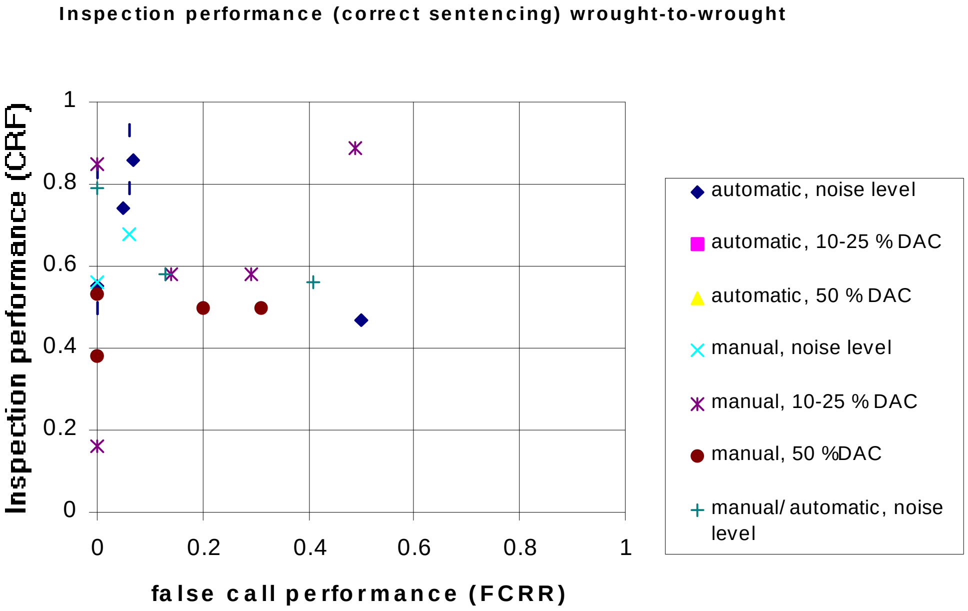


Figure 6.6: Importance of the false call rate in wrought austenitic steel piping

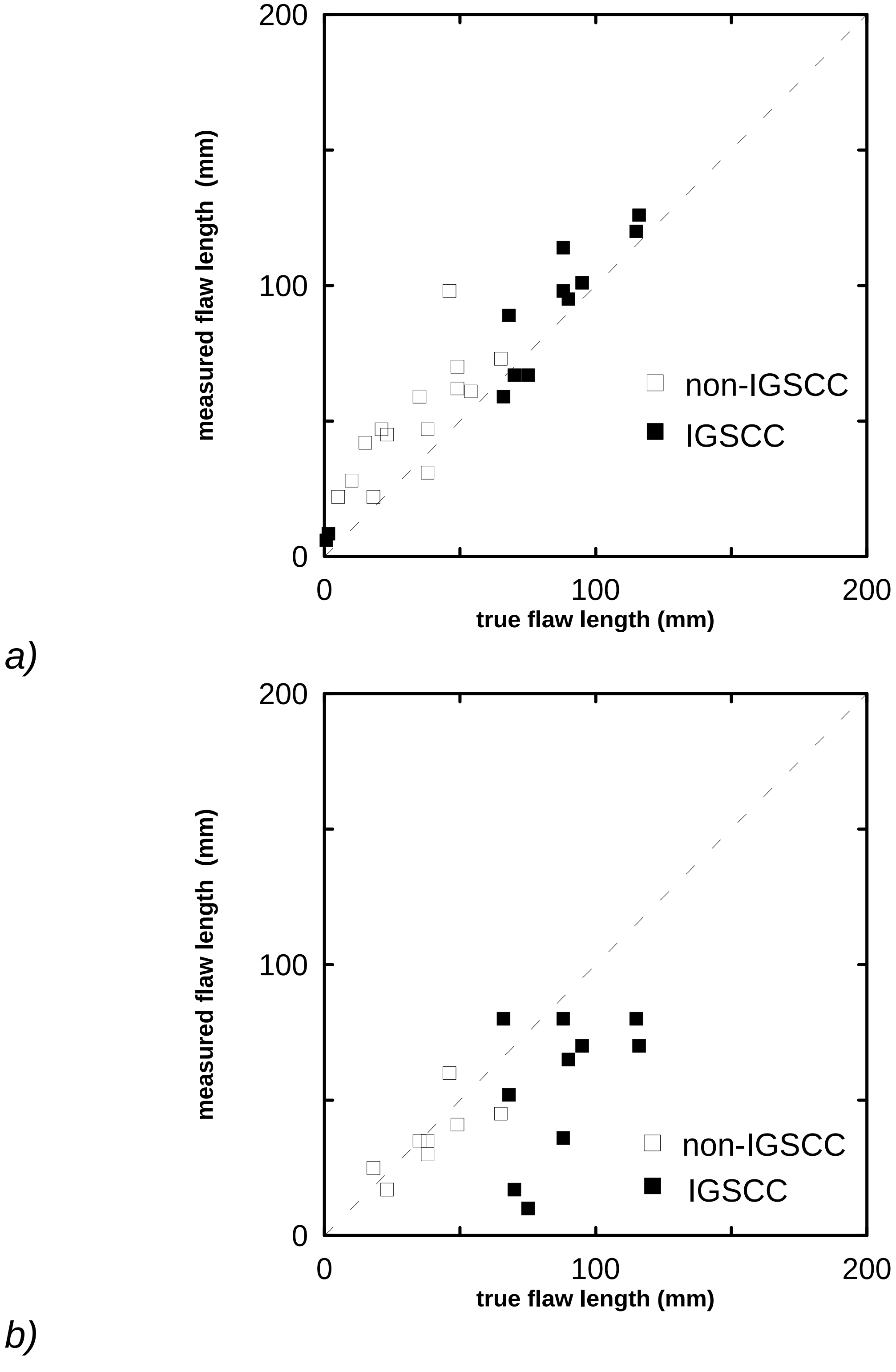
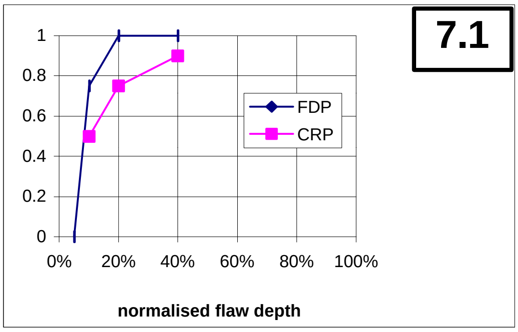


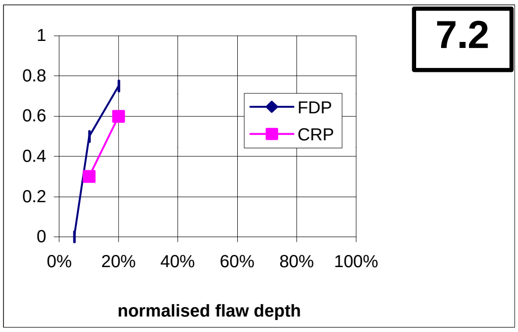
Figure 6.7: Length sizing. Typical examples of teams that a) did well (slope > 0.8 and correlation coeff. > 0.8) and b) did badly (slope < 0.5 and correlation coeff. < 0.5) (from PISC III REPORT No. 33, EUR 15663 EN).

a7Q	5%	10%	20%	40%	100%
FDP	0	0.75	1	1	
CRP		0.5	0.75	0.9	
MESD (mm)				0	
SESD (mm)				5	
MESL (mm)				0	
SESL (mm)				20	
FCRP				0	



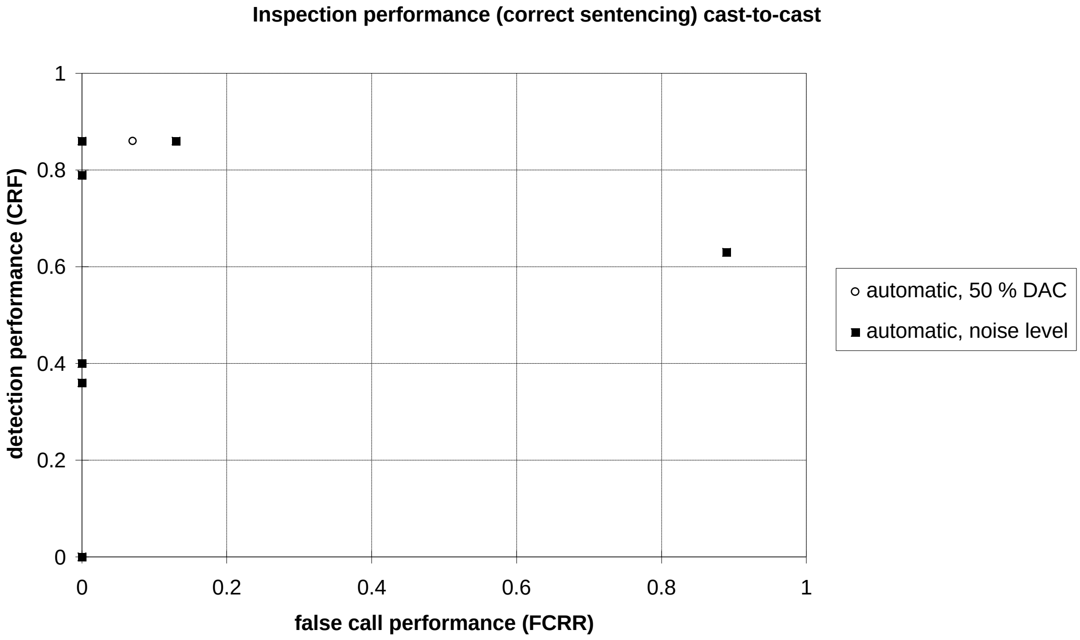
7.1

a7B	5%	10%	20%	40%	100%
FDP	0	0.5	0.75		
CRP		0.3	0.6		
MESD (mm)			2		
SESD (mm)			6		
MESL (mm)			0		
SESL (mm)			25		
FCRP			0.05		

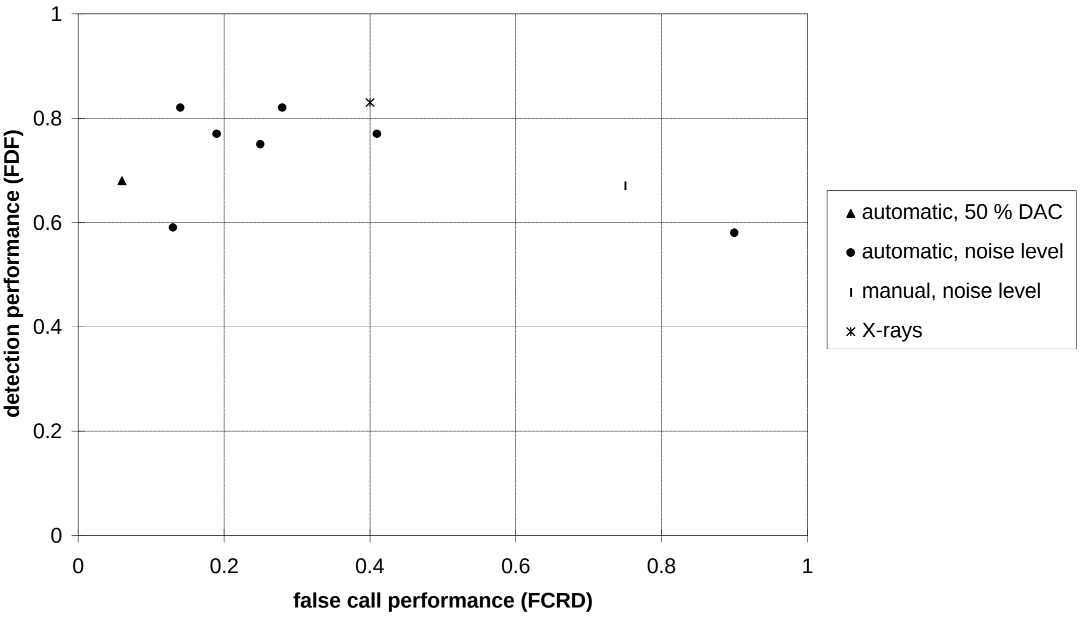


7.2

Figure 7: Inspection effectiveness for UT of large diameter cast austenitic steel piping



a)



b)

Figure 7.3: Importance of the false call rate for cast austenitic steel piping. a) FDR (safety) vs. FCRD (economical aspects); b) CRF (safety) vs. FCRR (economical aspects)

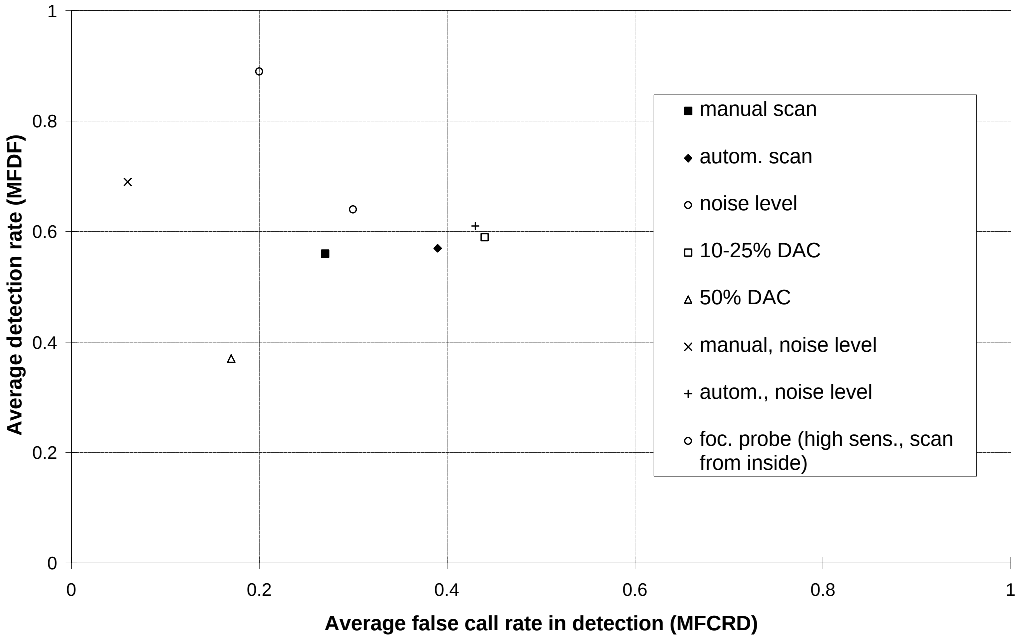


Figure 8.1: importance of the false call rate in safe-end assemblies (dissimilar metal welds)

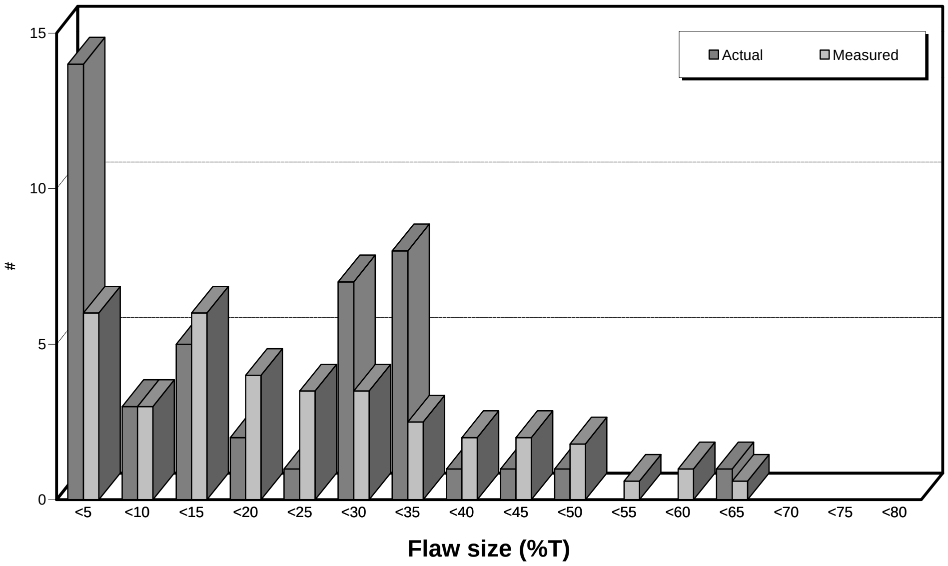
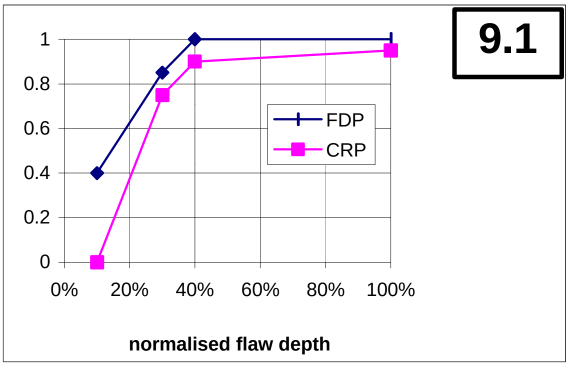


Figure 8.2: Flow dimension distribution as seen by the NDE operator after full inspection and as resulting from destructive examination (**‘expert vision’**).

d9Q	10%	30%	40%	100%
FDP	0.4	0.85	1	1
CRP	0	0.75	0.9	0.95
MESD (mm)				
SESD (mm)				
MESL (mm)			0	
SESL (mm)			4	
FCRP			0	



d9B	10%	30%	40%	100%
FDP	0.1	0.5	0.85	0.95
CRP	0	0.2	0.6	0.9
MESD (mm)				
SESD (mm)				
MESL (mm)			-3	
SESL (mm)			9	
FCRP			0.1	

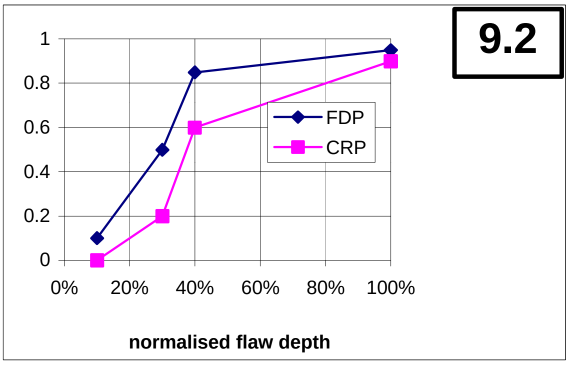
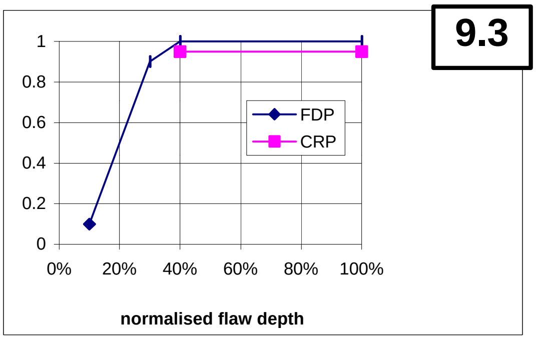


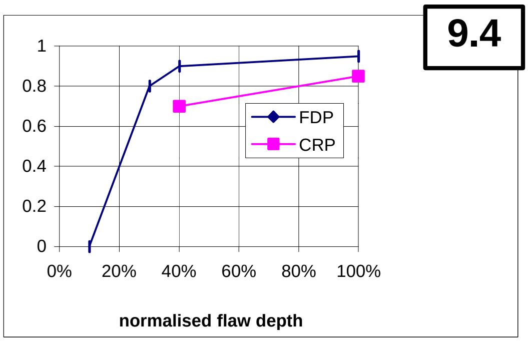
Figure 9.1-2: Inspection effectiveness for ET of austenitic steel tubes (steam generator). Cracks and planar defects only (PPD)

d9Q	10%	30%	40%	100%
FDP	0.1	0.9	1	1
CRP			0.95	0.95
MESD (mm)			-0.06	
SESD (mm)			0.1	
MESL (mm)				
SESL (mm)				
FCRP			0	



9.3

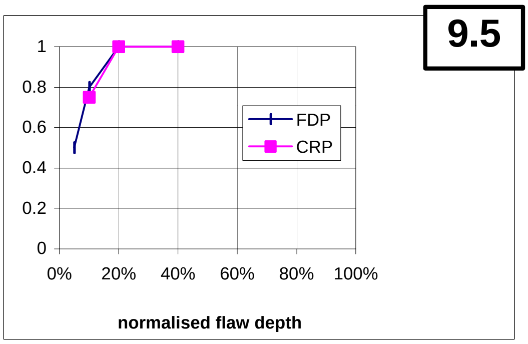
d9B	10%	30%	40%	100%
FDP	0	0.8	0.9	0.95
CRP			0.7	0.85
MESD (mm)			-0.1	
SESD (mm)			0.3	
MESL (mm)				
SESL (mm)				
FCRP			0.1	



9.4

Figures 9.3-4: Inspection effectiveness for ET of austenitic steel tubes (steam generator). Volumetric defects only (no IGA)

a9Q	5%	10%	20%	40%	100%
FDP	0.5	0.8	1	1	1
CRP		0.75	1	1	1
MESD (mm)					
SESD (mm)					
MESL (mm)				-1	
SESL (mm)				3	
FCRP				>.3	



9.5

Figure 9.5: Inspection effectiveness for UT of austenitic steel tubes (steam generator). Axial planar defects and cracks.

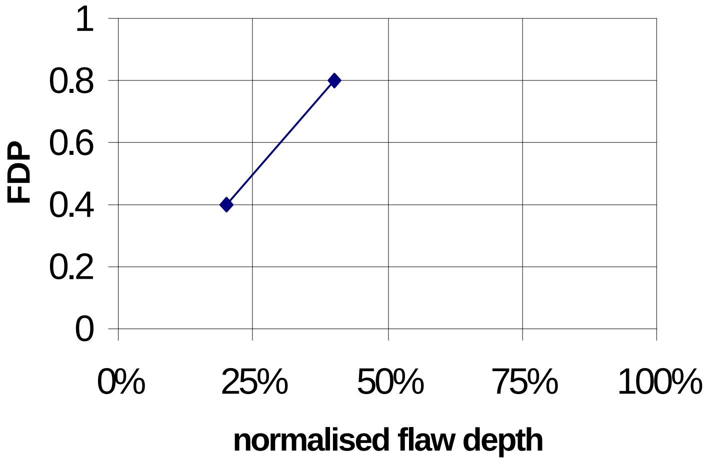


Figure 10.1: Effectiveness of ET inspection of ferritic tubes of heat exchangers.

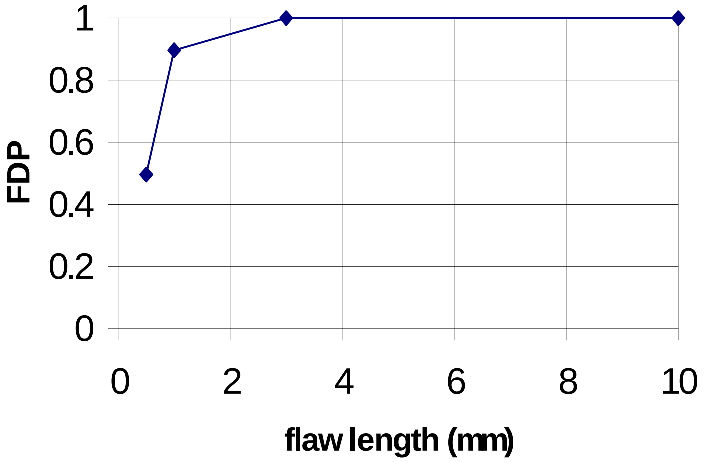


Figure 11.1 Effectiveness of ET inspection of thin plates

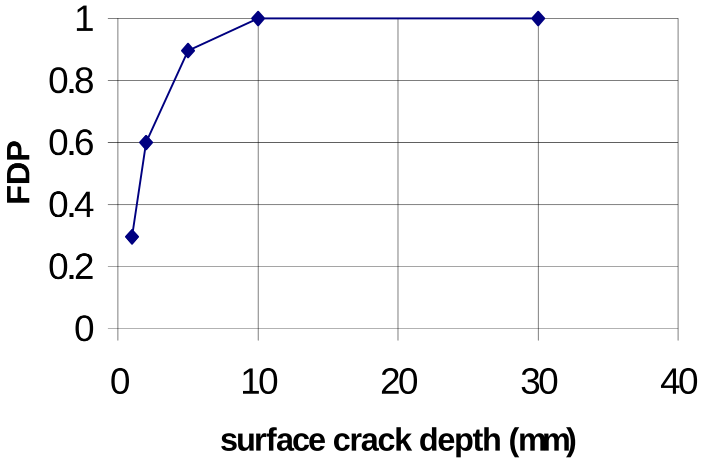


Figure 12.1: Detection performance vs. surface cracks using PT and MT techniques (good practice; confidence limit at 95%: see chapter 4.3)

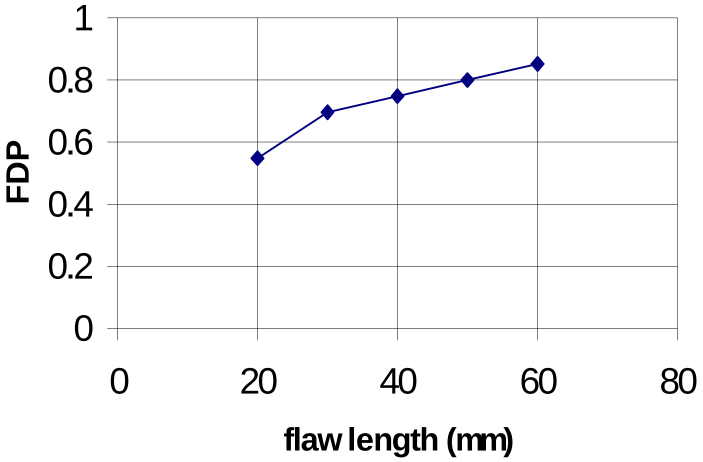


Figure 12.2: Detection performance vs. surface defect length using MT (good practice surface inspection)

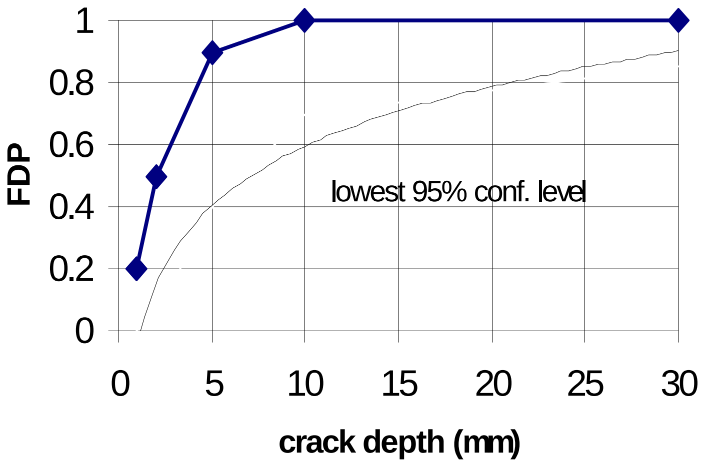


Figure 12.3: Surface crack detection performance vs. defect size in depth for ET used as surface inspection technique in ideal condition. Lowest 95% confidence level is the one of the less performant trial in the UCL project.

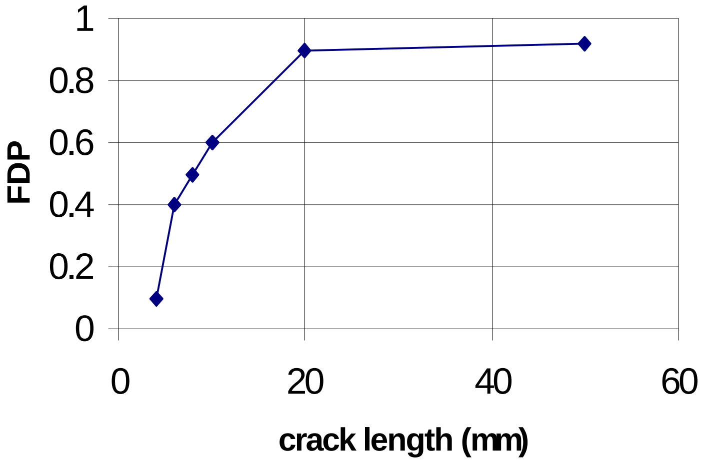


Figure 12.4: Detection performance vs. defect length for Eddy Current technique used as ‘surface’ in ideal conditions.

f12b (ACFM)	1	2	5	10	30
FDP	0.6	0.8	1	1	1
MESZ			2.5		
SESZ			2		

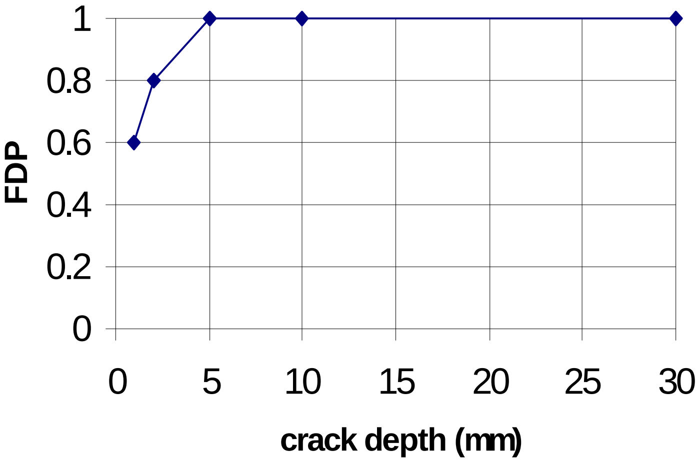


Figure 12.5: Surface crack detection using ACFM complemented with ACPD for sizing

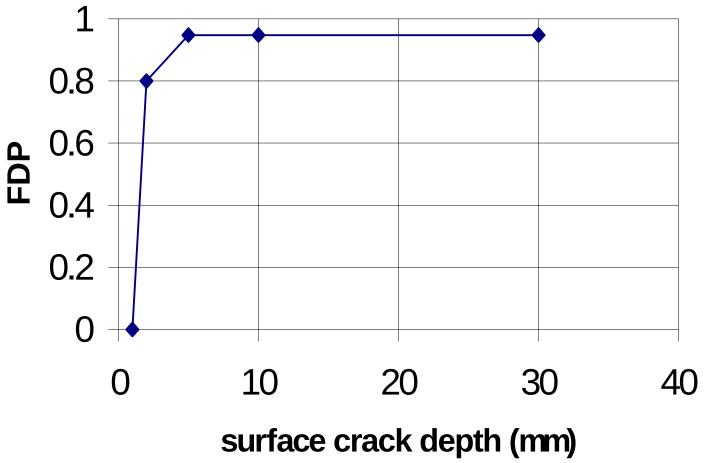
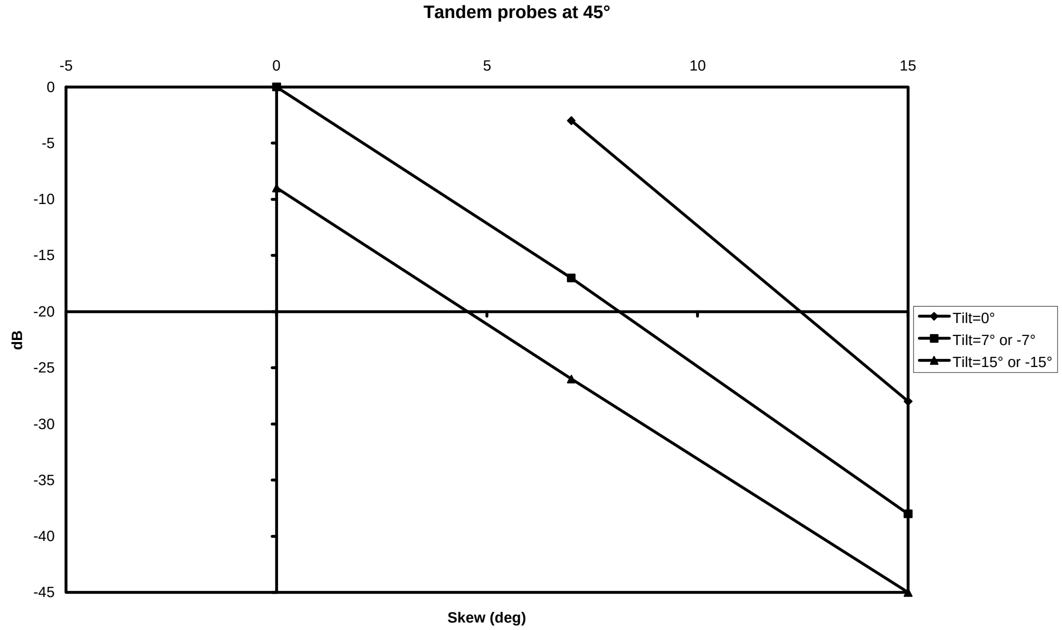


Figure 12.6: Surface crack detection using accessible component surface using the UTCW technique



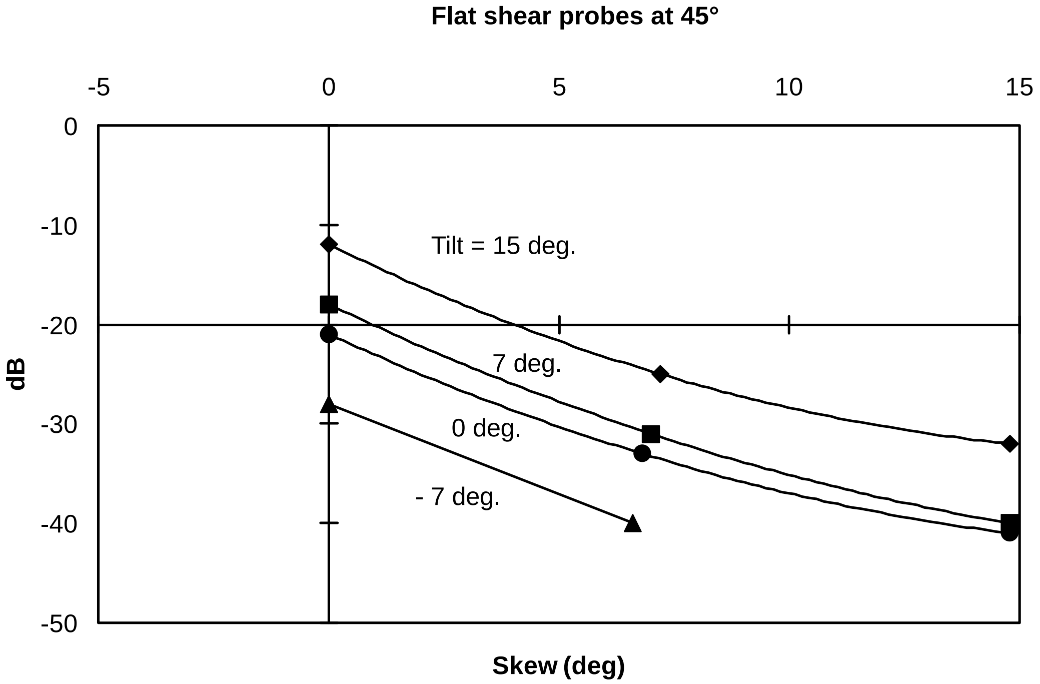


Figure 13.1: Combined effect of tilt and skew angles on the defect response in amplitude. Defects are smooth planar cracks with sharp crack tip. D=25 mm. Position in depth of the defect: 100 mm (L=100 mm) in the vessel wall (PISC II parametric study)

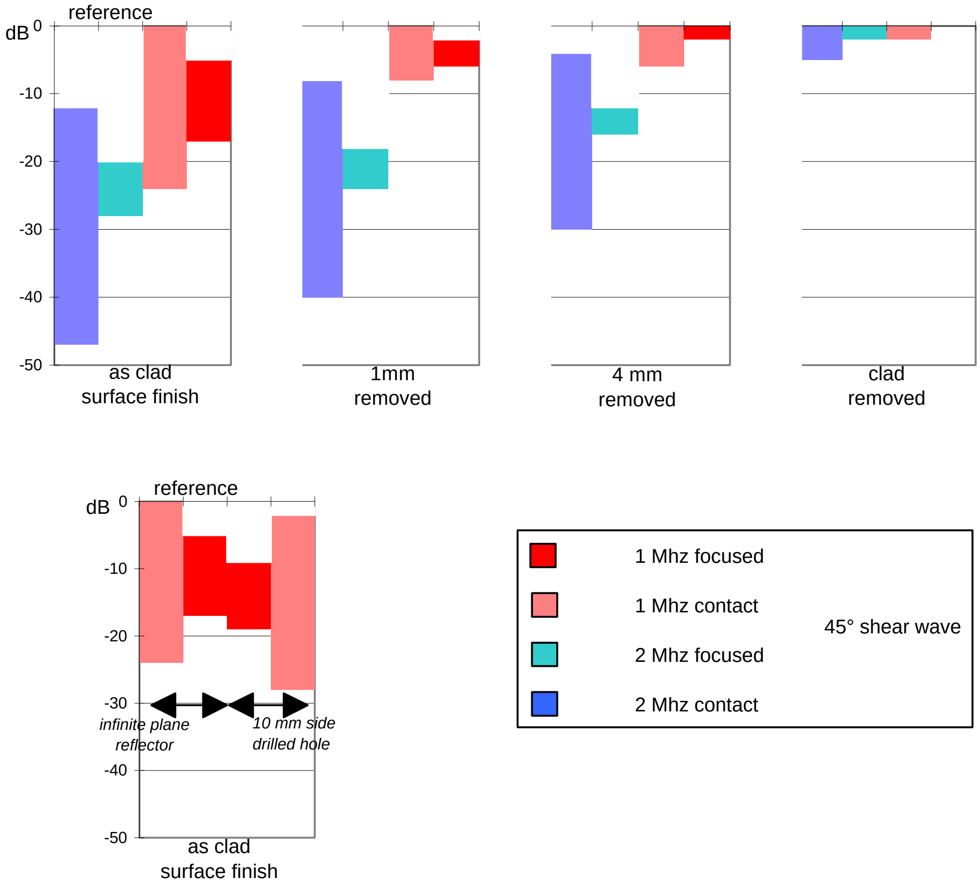


Figure 13.2: Effect of the cladding characteristics (surface finish and thickness) on the amplitude of response of side drilled holes and back walls (PISC II parametric studies).

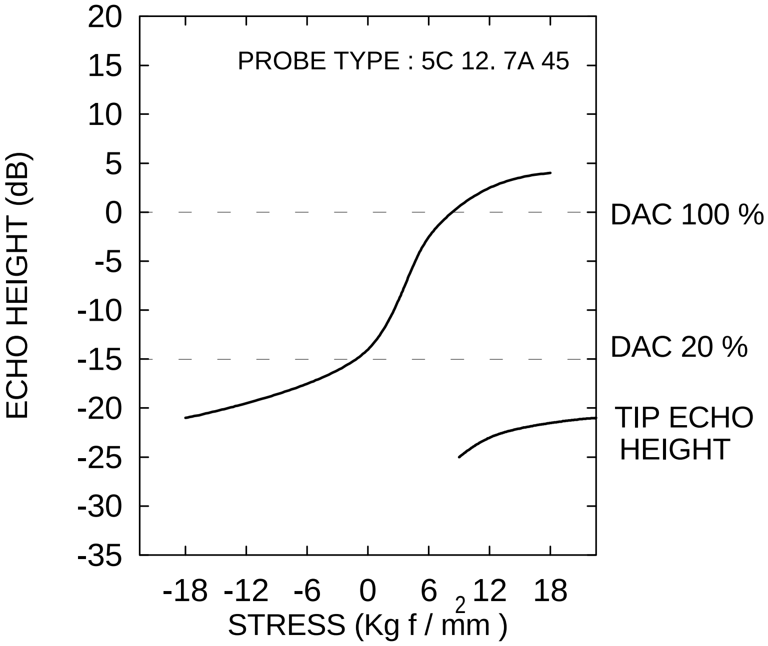


Figure 13.3: Example of the importance of compressive stresses on a sharp planar fatigue crack response in amplitude (from: Shibaura Inst. of Tech./ NPE test centre / Hitachi, Ldt, Japan)

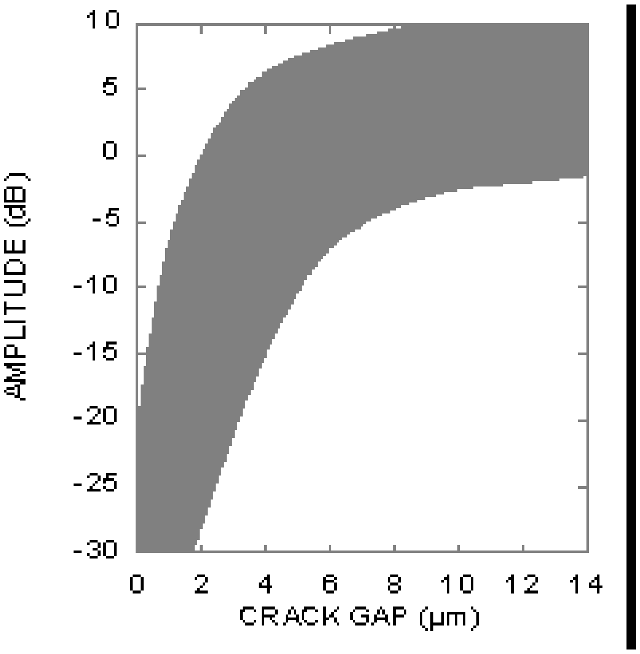


Figure 13.4: Relation between crack with (e.g. crack opening at half depth) and the amplitude response (from: Shibaura Inst. of Tech./ NPE test centre / Hitachi, Ldt, Japan)

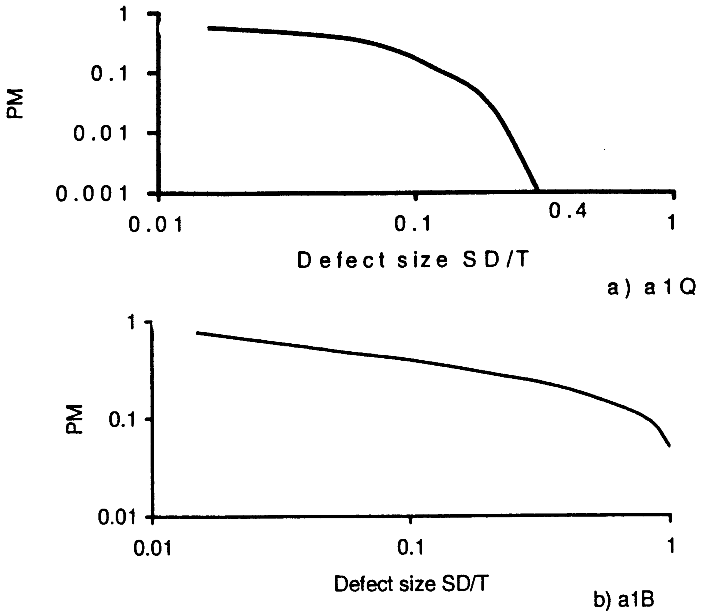


Figure 14.1: Example of probability of missing a defect (PM) in a vessel weld inspection with qualified procedures (a.1.Q) and good standard procedures (a.1.B).

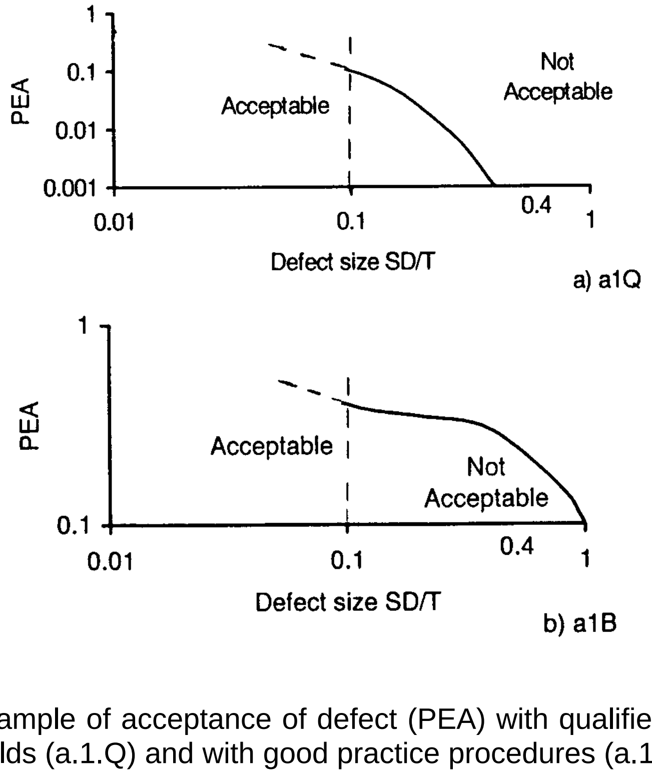


Figure 14.2: Example of acceptance of defect (PEA) with qualified procedures for vessel welds (a.1.Q) and with good practice procedures (a.1.B)

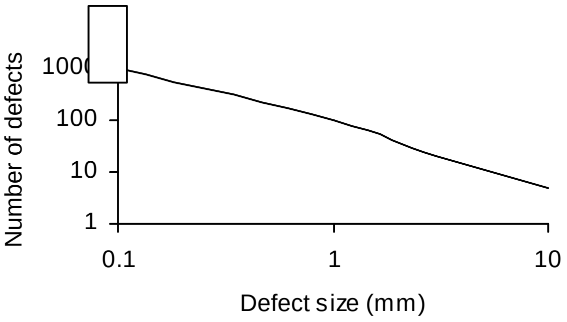


Figure 14.3: Approximate fabrication defect presence for 15m of weld in PISC assemblies (pressure vessels)

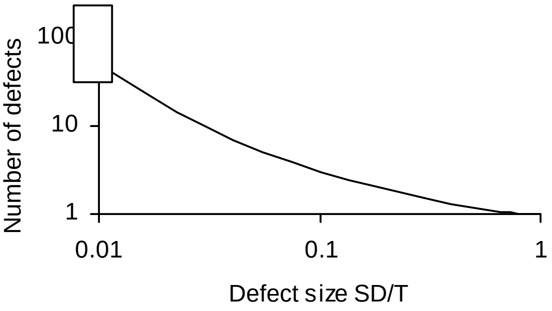


Figure 14.4: Postulated presence of planar type defects resulting from service for 15m of weld in vessels, before any inspection

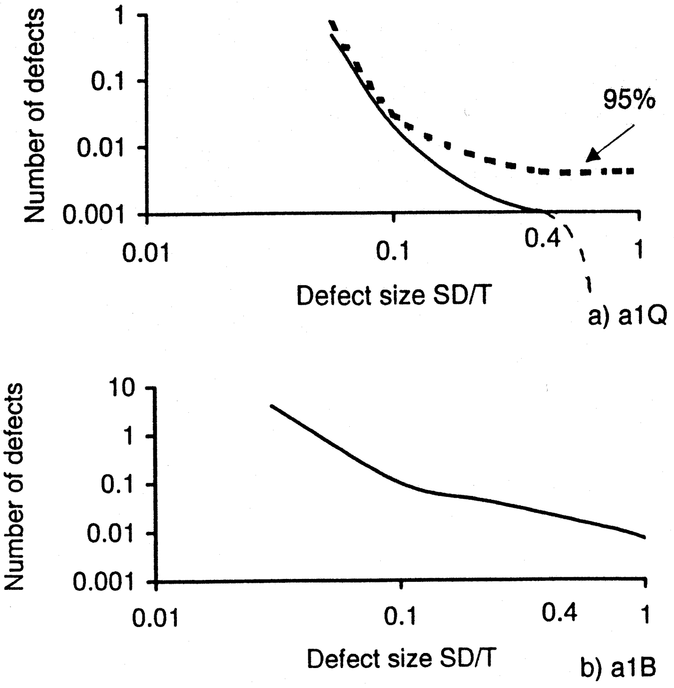
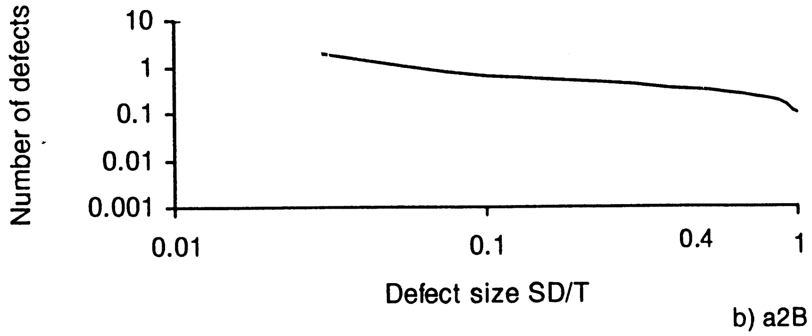


Figure 14.5: Presence of defects after inspection conducted following a strict qualification procedure and a good practice procedure for 1m of vessel weld.

a) a2Q



b) a2B

Figure14.6: Hypothetical defect distribution in large diameter piping weld zone, along the experience gained in the PISC program and for 10m of weld using qualified inspection (a) or good practice (b).

Appendix 2: Inspection qualification

Introduction

Since the early sixties, inspection of structural components has been harmonised through prescriptive codes and standards. (e.g. ASME code). Exercises such as PISC demonstrated that inspection conducted according to ASME was subject to low effectiveness, and it was inadequate for critical applications.

Code and standard bodies involved in these exercises, as well as plant owners, regulators and R&D institutions, started very soon to press for the demonstration of capability of inspection techniques on mock-ups like the ones used for the Round Robin Tests of PISC.

The idea of demonstration of effective performance came to the fore early : in 1975 in the ASME NDE Task Group; in 1979 in the PISC I group ; in the early 80s in UK as a result of PISC and DDT (Defect Detection Trials) and in view of the public inquiry for Sizewell B. The IVC was created at Risley (AEA Technology) in 1982 ; a programme on NDE performance demonstration was accepted by ASME Section XI in 1987 and Appendix VIII of Section XI was issued in 1989.

Starting in 1990 / 91 several European countries began to develop programs or working groups on NDE performance demonstration: in 1987, JRC, operating agent of PISC, proposed to embark in a programme called EBIV (European Bureau of Inspection Validation), which was officially created as a European network in 1992 and renamed ENIQ (European Network for Inspection Qualification) in 1993. Performance demonstration was then called qualification in the European Union and Switzerland. ENIQ issued the first edition of the European Methodology for Inspection Qualification in 1995.

Nuclear Regulatory Authorities in the European Union and Switzerland created a task force on NDE qualification in 1993 to express their common positions on inspection qualification in 1996.

Qualification of inspection procedures is a way of harmonising inspection requirements. Through qualification, it is possible to be with equally open to any inspection technology; qualification is based on performance standards which, in opposition to prescriptive standards, allow the use of any technique which satisfies the inspection objectives in the environment considered.

These performance standards also allow any service company -small, medium or large- from any country to offer inspection services, if successful during demonstration exercises called qualification. The qualification methodology -if applied by qualification bodies recognised capable of such technical performance and accepted by the clients and / or by the regulatory bodies- thus allow fair competition and ensures a consistent and predetermined level of effectiveness of inspection.

Safety objectives (or plant availability objectives), if correctly expressed as a function of the component, its materials and of the environment, can then be translated into inspection objectives, which, obviously, will be different from situation to situation, even if the safety objectives are fundamentally equivalent. Inspection objectives define performance targets for the inspection procedures : detection, location, classification and sizing of relevant defects in the component. Such performance targets can be used as a capability level that the inspection procedure must reach. The qualification of the procedure will be the tool for verify the performance capability.

Qualification in SINTAP

The present report does not imply that all NDE procedures used in industry must be qualified. However, qualification does effectively fix the NDE performance level. If NDE performance needs to be quantified as an input to a structural assessment, then some form as qualification will, almost certainly, be required. This applies to the detection performance, as well as to the capabilities for defect sizing, classification and location.

In the presentation of results, the most important diagram or figures given refer to results after qualification of the techniques or procedures. This should ideally happen, in the future, for any application of NDE; qualification can be applied in different ways depending on the situation, and at low cost particularly if it I not refereed by an external authority.

Appendix 3: Coding of results

The presentation of results given in appendix 1 follow the codes below.

a	1	B	FDF
NDE procedure	component	NDE level	variable (effectiveness

NDE Procedure (or technique)

a. Usual UT procedure based on good practice
b. low effectiveness UT procedure (e.g. 50% DAC, 1 technique)
c. Advanced UT procedure
d. ET procedure
e. RT procedure
f. Industrial surface inspection techniques (MT, DT, ET, ACFM, UTCW,…)

Component

1. Pressure vessel welds or flat plates. Carbon steel. T > 75mm
2. Large diam. piping or PV or flat plates. Carbon steel. D > 250 mm, 30mm < T< 75mm
3. Large diam. piping or PV or flat plates. Carbon steel. D > 250 mm, 10mm < T < 30mm
4. Small diam. piping, carbon steel. 50 < D < 250 mm ; 5mm < T < 30mm
5. large diam. piping, wrought s steel. D > 250mm, T > 30 mm
6. Small diam. piping, wrought s steel. 50 < D < 250 mm, T < 30 mm
7. Cast s steel piping or elbow. 20 < T < 80 mm, 250 < D < 800 mm
8. Dissimilar metallic welds zones. 20 < T < 80 mm, 250 < D < 800 mm.
9. Austenitic steel tube. 2o < D < 50 mm, 1 < T < 5 mm
10. Carbon steel tube. 30 < D < 50 mm, 1 < T < 5 mm
11. Flat plate. T < 5 mm.
12. Surfaces of components suitable for surface inspection

NDE level or way of evaluating the effectiveness

B. Blind testing (RRT). AVERAGE VALUE.

Q. Results credible in industrial applications only if a qualification programme sets such a capability !

Variables

FDP : detection probability
CRP : correct rejection probability
MESD / SESD : average error of sizing in depth, standard deviation
MESL / SESL : average error of sizing in length, standard deviation
FCRR : false call rate leading to rejection.