INFORMATION FOR THE PROCUREMENT AND CONDUCT OF NDT

Part 3: Radiographic Inspection in Industry

April 2008

1. INTRODUCTION

Following the successful production of the Health and Safety Executive (HSE) documents describing best practice for the procurement and application of manual ultrasonics [Ref. 1] and magnetic particle and dye penetrant inspection [Ref. 2], the HSE have judged it appropriate to issue further documents. These will identify when problems can arise in the selection and application of other NDT methods and what solutions might be adopted.

The information contained in this document is recommended by the HSE for the conduct of radiographic inspection in industry. It is intended to promote the adoption of good practice whenever radiography is used, which is mainly in the inspection of new plant but also for in-service inspection. The document is oriented towards the inspection of welds because these are a very common subject for radiography but the principles it contains are equally applicable to all component types. The information applies both to inspections carried out by the NDT department of the company owning or manufacturing the plant and to those carried out by external NDT organisations under contract. In the latter case, they are intended to assist in the procurement process by highlighting the issues that need consideration. In addition, the information draws attention to the possibility that radiography may not be the most appropriate inspection method and they identify when other methods should be considered.

This document is not intended to replace the relevant technical standards or to supersede them in any way. It identifies the many factors which are important in the choice and application of the method, including technical ones. However, it does not provide any direction on the values to be adopted for the different technical parameters other than to reiterate in some cases what is in the standards. Detailed definition of inspection parameters is the role of the detailed technical standards and the specific procedures derived from them. The document also identifies important issues beyond those covered in standards such as organisational matters and provides recommendations on these.

The document has been drawn up by a committee of experts assembled by the HSE for this purpose. Their names and affiliations are given in Appendix 1, from which it will be apparent that they represent a very wide range of those parts of British industry using the relevant NDT methods. In addition, they have considerable expertise in and responsibility for the application of NDT to industrial plant. The recommendations contained in this document are based on two main sources. The first is a literature search and subsequent review of relevant published papers and articles regarding the reliability of the application of radiographic inspection. The second basis for the recommendations is the collective experience and expertise of the committee mentioned earlier. Many of the members were also members of the PANI Management Committee (Ref. 11) and the committees responsible for both the previous best practice documents. Both sources of information support the view that, if incorrectly chosen or incorrectly applied, radiographic inspection methods can be ineffective.

Two studies on the inspection of welds in steel components illustrate the poor detection that can result from the application of 'standard' techniques. The NORDTEST trial results [Ref. 3] performed on over 3,000 X-ray radiographic interpretations of a total of over 700 defects gave an overall average probability of detection of about 70% for the highest sensitivity level. In a NIL study [Ref. 4], standard single shot radiography of welded plates up to 15 mm thick using X- and γ-rays gave probabilities of detection ranging from 60 to 70%. However, when x-ray radiography was performed with two separate shots aligned with the fusion faces the resulting probability of detection was 95%. This was probably because the beam was aligned with lack of fusion defects in the welds. However, it is not clear whether a failure to detect a defect in the latter exercise arose from the fact that no image was produced by the technique used or whether the image was mis-interpreted. Consequently no detailed conclusions can be drawn from these results and they are cited here simply to illustrate that radiographic performance can sometimes be less than the optimum which is possible. Such results and others, together with the experience of the members of the committee, provide the incentive for production of this document.

Section 2 of this document contains notes on the way a radiographic defect detection method is chosen, depending on the particular circumstances of the inspection. It also describes the different ways in which the methods can be applied in practice and the factors which determine how the choice is made. Section 3 contains a review of the current way in which most radiographic inspections are designed and carried out and the way in which the quality of the inspection is assured. Section 4 provides an analysis of potential problems in the application of radiography together with a list of the measures which can be adopted in response. In doing this, it is recognised that the extent to which it is reasonable to include additional features in the inspection, and incur additional costs as a result, depends on the role of the inspection in assuring plant safety, the economics of the inspection activity and the consequences of the inspection failing to achieve its objectives. Accordingly, Section 5 contains a discussion on how the effectiveness required of the inspection can be assessed and on how this then affects the adoption of the additional inspection measures identified in Section 4. Finally, Section 6 highlights safety issues associated with the application of radiographic inspections.

2. GENERAL FEATURES OF RADIOGRAPHIC INSPECTION

Radiography is widely applied for the detection of both volumetric and planar defects in both new and existing plant.

2.1 Technique

The basic technique is illustrated in Figure 1. The dimensions shown are not to scale. In particular, it should be noted that the object to film distance is normally reduced to the minimum possible.

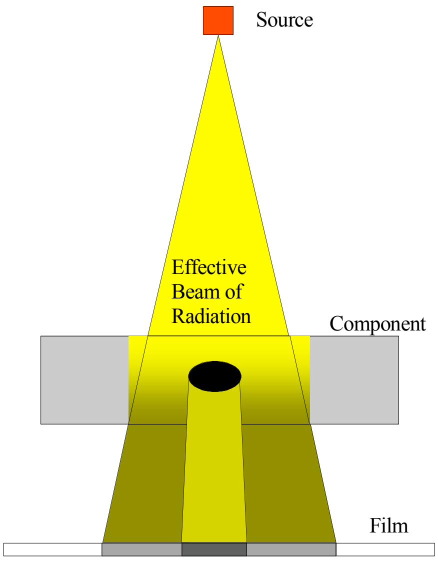


Figure 1 Schematic Diagram Showing the Principle of Radiographic Inspection

Radiation from the source passing through any defects in the component under test is less attenuated than adjacent rays through unflawed metal and so darkens the film more.

2.2 Application of Radiographic Methods in Practice

2.2.1 Source Type

Industrial radiography typically uses photographic film to record the two-dimensional x-ray or gamma ray transmission profile through the material undergoing examination. To maximize the contrast between defects in the inspected material and parts that are unflawed, it is necessary to choose an x-ray or gamma energy that is high enough to penetrate a flawless specimen at a level that will blacken the film just sufficiently to reach the bottom end of its sensitivity curve.

The art here is in achieving the maximum optical density contrast in the photographic film for regions exposed to radiation transmission through flawed and unflawed parts of the material undergoing examination.

Therefore, thick materials will require a higher energy radiation than thin materials for a given defect size detection capability. Since x-rays are typically of lower energy than gamma rays, they are more suited to examination of thin materials up to around 50mm of steel. At thicknesses greater than 50mm, many gamma ray sources become increasingly more suitable than x-rays as the material thickness increases.

A guide to the source type to be used at different steel component thickness is given in the appropriate standard and is shown below [Refs 5, 6, 9]:

Thickness	X-Ray Energy Range	γ-Ray Source
≤ 5 mm	Up to 130 kV	Thulium 170
1 - 15 mm	Up to 230 kV	Ytterbium 169
10 - 40 mm	175 - 410 kV	Selenium 75
20 – 100 mm	275 kV – 4 MeV	Iridium 192
40 – 200 mm	410 kV – 4 MeV	Cobalt 60

It should be emphasised that the values above are only indicative. Precise source requirements can only be derived from consideration of the requirements of each specific case.

2.2.2 Film Types and Viewing

Commercial radiographic film is available in a range of grain size and speed, the faster films having the larger grains and hence the grainier images. Radiographic standards specify film type in terms of grain size and contrast. The film density is related to the exposure it has received and the gradient of the curve of density against exposure determines how visible are small changes in exposure. Such changes can arise from the presence of defects and so the ability to detect them through changes in film density is of prime importance. This characteristic of the film is its contrast.

Contrast tends to increase with film density and so high densities are beneficial in the detection of defects. However, viewing high density films requires good lighting conditions such as high light intensity, low background light and film masking and there are practical limits on the level to which density can be increased because of the reduction in transmitted light intensity. Film density is defined as:

$$\log_{10}\{\text{incident light intensity/transmitted intensity}\}$$

Density in the range 2.0 – 3.0 is usually regarded as representing the best compromise between contrast and viewing requirements.

If an image of satisfactory quality cannot be obtained with film of a given speed, it is possible to use slower film to improve quality but at the expense of increasing the exposure time.

2.2.3 Film and Source Positions

The general requirement for positioning the source and film is that the beam should be directed to the middle of the area under examination and perpendicular to the surface. However, if the component is being checked for defects at known orientations such as lack of side wall fusion in welds, it will be beneficial to direct the beam as nearly along the plane of the defect as possible as discussed in the Introduction. Also, as discussed below, when inspecting pipe or tube welds there are circumstances where it may be of benefit to direct the beam differently.

When inspecting pipes/tubes (henceforth referred to simply as pipes), there are three possibilities for the position of the source and the film:

- Film outside, source inside
- Film inside, source outside
- Both film and source outside

In the last case, the radiation has to pass through the pipe wall twice and there are two ways in which the arrangement can be implemented:

Double wall, single image. In this arrangement the source is offset sideways from the nearest part of the weld so that the beam passes through parent material on the near side of the pipe and also through the part of the weld on the far side of the pipe producing an image of this part of the weld only.

Double wall, double image. Here the source is positioned further from the pipe and is also offset as before, but not sufficiently for the beam to miss the nearest part of the weld. As a result, images of the weld at both the near and far side of the pipe are produced at different points on the film and fewer shots are needed to inspect the entire weld circumference. The maximum pipe diameter allowed in the relevant standards for use of this technique is 89mm.

Double wall methods cannot produce as good a flaw sensitivity as single wall methods and so the latter are preferred if the geometry and access arrangements permit.

A number of competing considerations apply to the determination of the source to film distance. First, the geometric unsharpness, which determines how well defined an image appears on the film, decreases as distance increases. However, because of the lower radiation intensity, longer exposure times are needed unless higher output radiation is used. The latter would decrease contrast which may completely offset the gain in definition. In practice, compromises are adopted and the radiographic standards [Refs 5, 9] give recommended distances for different circumstances. These are influenced by the source type, the film type and the component curvature. The greater the distance between the source and the and the component, the greater the radiation risk for site radiography.

The other parameters which affect geometrical unsharpness are source size and object to film distance. As small a source as practicable is normally used to minimise unsharpness. Also, it is desirable for the film to be placed as close to the component under inspection as possible. When a gap is unavoidable, a correction should be made to the film to source distance calculated as discussed above. This correction is given in the standards.

2.2.4 Image Quality Indicators

All radiographic standards require the use of an image quality indicator (IQI) to provide a guide to the quality of the radiographic technique used. IQIs are commonly of the wire type, comprising straight wires of differing diameters sealed in a plastic envelope, or ones which use holes or steps in a block of metal. The IQI is placed on the object under test and imaged when the radiograph is taken. The smallest wire diameter, hole diameter or step that is visible on the radiograph then gives a guide to the sensitivity achieved. The IQI type and its position are specified in the appropriate radiographic standard. It should be recognised that the sensitivity established by an IQI relates only to the ability to detect changes in section, wire size etc.. This sensitivity is only indirectly related to defect detectability.

2.2.5 Intensifying Screens

The use of intensifying screens is specified in radiographic standards. These are placed on both sides of the film and have the effect of reducing exposure times and improving image quality. The screen material and thickness is given in the standards for the different sources that are used.

2.2.6 Identification

It is important to identify each radiograph so that the position in the component from which it came is unambiguously clear. To this end, it is recommended in the standards that each radiograph is permanently marked. This can be done using lead letters and numerals which are positioned so that their images appear in the radiograph. It can also be done using darkroom applied flash identification. The purpose in all cases is to identify:

- The job or workpiece
- The joint
- The section of the joint

It is also recommended that workpieces are permanently marked to allow relocation of the position of each radiograph. The way in which this is done must be the subject of agreement with the plant owner.

2.3 Modern Trends

2.3.1 Dose Reduction Systems

A number of systems have been developed to reduce the dose rates to inspectors and also to limit the extent of the adjacent area subject to safety restrictions. Adoption of such systems leads to less disruption to other work adjacent to the radiographic site. The way in which this is achieved is through the exercise of greater control of the radiation emitted, particularly by eliminating the risk from the transient dose in the way the source is exposed. As an example, Small Controlled Area Radiography (SCAR) is one of the proprietary radiographic systems which embody the principles above. Proper application of such systems can reduce the controlled area to typically within 3 metres of the radiation source.

2.3.2 Real Time Radiography (Radioscopy)

Radioscopy is the production of an image by ionising radiation on a radiation detector such as a fluorescent screen or an array of solid state sensors which is then displayed on a television or computer screen. Often such systems work in real time and can provide continuous inspection of objects. The recent advances in detectors and computer technology mean that these systems can offer advantages over the conventional film inspection technique. However, radioscopy systems are normally more suited to fixed installations rather than on-site use with mobile equipment.

Standards governing the general principles and equipment performance have been issued (Ref. 12) and should be referenced in any application as with film radiography. A written procedure should be agreed between the purchaser and the supplier of radioscopic services which, in general, covers the following requirements:

1) Equipment Qualification – The system features must be qualified to ensure that the system is capable of performing the examination.

2) Test Object Scan Plan - A list detailing the test object orientations, ranges of motion and manipulation speeds to ensure a satisfactory examination.

3) Radioscopic Parameters - Energy source, intensity, focal spot, source to object distances, object to image and source to image distances.

4) Image Processing Parameters – Details of image processing variables to enhance defect detectability and specified sensitivity.

5) Image Display Parameters – The techniques and intervals to be applied for video image display i.e. brightness, contrast, focus and linearity.

6) Acceptance Criteria – Details of imperfections and rejection levels.

7) Performance Evaluation – Details of qualification tests and intervals to ensure a suitable examination is carried out.

8) Image Archiving Requirements – Details for preserving a record of the examination results.

9) NDT Qualifications – Details of the NDT Operators' qualification requirements.

2.3.3 Digital Filmless Radiography

Industrial radiography using computer based or "filmless" radiography systems can collect and analyse radiographic data, completely replacing conventional film in some applications e.g. process corrosion detection and measurement, particularly under insulation and coatings on process pipework. This technology complements non-projection systems like SCAR to provide a safe, rapid inspection. The system uses flexible, re-usable phosphor plates to capture images. The exposed plate is processed through a laser scanner, delivering the image to a high resolution mono-monitor. After scanning the plate, the digital image is interpreted, reported and digitally stored for future retrieval and analysis.

The flexibility of this approach means that extra control is required of the process to ensure radiographs are traceable and not distorted, deleted or over-written.

3. CURRENT PRACTICE FOR DESIGN AND CONTROL OF INSPECTIONS

Many radiographic inspections are designed on the basis of a national or international standard such as BS EN 1435: 1997 [Ref. 5]. The status of the various standards as of January 2005 is given in Appendix 2. The procedure for the inspection is frequently written to reflect simply the requirements of the standard in terms of the application of the equipment and the consumables. However, procedures are often supplemented by technique sheets which are provided to reflect specific plant and technique details for a particular component. Clearly different components need different technique sheets.

Operators are trained and qualified according to the requirements of a qualification scheme based on international standards such as BS EN 473 [Ref. 7] or ISO 9712 [Ref. 8]. Qualifications can be awarded for production of radiographs and, either separately or jointly, for their interpretation. The former typically require operators to pass a written examination and to demonstrate their practical skill on test pieces containing defects. For radiographic interpretation, operators are required to demonstrate their practical skill on radiographic images. Different interpretation qualifications are available for different types of inspection e.g. light and dense materials, x- and γ-rays. It may be the case however that the test pieces or images on which an operator qualified may not be directly relevant to a particular inspection, geometry or defect.

The authority to approve a procedure for a specific inspection based on the more general requirements of a code or standard requires skills and qualifications additional to those required of the operators who apply the inspection in the field. Such qualifications are denoted as Radiographic Testing (RT) Level 3 and involve demonstrating a greater understanding of the particular inspection method than expected of the Level 1 or 2 operators who normally carry out the inspection. The Level 3 inspector also has a good knowledge of other NDT methods. Complete definitions, for one particular qualification scheme (PCN), of the areas in which operators at Levels 1, 2 and 3 have demonstrated competence and the tasks they might perform are given in Appendix 3.

The approach outlined above can be effective in certain circumstances and represents a cost effective way of defining and implementing requirements for radiographic testing. However, there are circumstances in which it can lead to the adoption of unsatisfactory inspection procedures or to the use of operators whose training and qualifications are inappropriate to the particular inspection. It is crucial that such circumstances are recognised and appropriate additional requirements are specified. These are discussed below.

4. THE NEED FOR ADDITIONAL REQUIREMENTS

In this section, potential problems identified by both the review of previous studies and the committee of experts described in the Introduction, are discussed. In each case, the issues identified are followed by a number of recommendations to address the particular difficulty. It is not intended that all these be adopted in every case. Instead it will be necessary for those responsible for each inspection to determine which recommendations are appropriate. Advice on making a selection is included in Section 5 of this document.

4.1 Defect Type

Consideration of the defect parameters is important in selecting the appropriate radiographic technique to apply and then in ensuring that it is applied correctly. The first requirement is to ensure that all parts of the component in which defects can occur are inspected adequately. This requires careful control of source and film positions but also a complete knowledge of the potential incidence of any defects.

The Nordtest results given in reference 3 clearly demonstrate that volumetric defects are more readily detected than planar ones. This is to be expected because of the greater tolerance to beam direction of volumetric defects. The most important defect parameters for radiography are size, morphology, orientation and opening (gape). Reference 10 shows that for cracks with small gapes, the tolerance to misorientation is reduced below that for wider cracks. Thus, planar defects are most reliably detected in general by beams as nearly parallel to the plane of the defect as possible. If it is impossible to introduce beams in the required way, consideration may need to be given to the use of a different inspection method.

<u>Recommendations</u>

- The defects of concern and their relevant parameters should be identified by the plant owner as a basis for inspection design.
- Radiographic procedures should be designed taking defect parameters into account.
- The volumes of components under test in which defects can occur should be established to ensure that the radiography includes all suspect areas.
- The radiographic beam should be aligned as closely as possible to the likely plane of planar defects.
- When planar defects can occur in a range of orientations, consideration should be given to using multiple shots with the source in different positions. The aim should be to align the radiographic beam as closely as possible with the plane of the defect.
- If it is not possible to introduce the radiographic beam at an appropriate angle for the defects of concern, consideration should be given to using a different inspection method.

4.2 Component Geometry and Access

Section 2 of this document discusses the various factors which affect the quality of radiography and the way that the standards define a range of values for the various key parameters depending on the precise conditions applying . When producing a procedure for a specific inspection it is necessary to determine the various parameters on the basis of the specific component being inspected. Component thickness will determine the nature of the source it is appropriate to use. Availability of access to the various surfaces and the geometry of the component will determine the appropriate radiographic configuration. The precise radiographic arrangements can then be determined from among the range of possibilities included in the appropriate standard. When inspecting pipes, double wall techniques should be avoided unless access arrangements do not allow a single wall approach.

<u>Recommendations</u>

- Radiographic procedures for specific components should be developed from the appropriate standard taking account of the precise dimensions, geometry and access arrangements which apply.
- It should be recognised that certain component geometries, e.g. fillet welds, can pose major problems for radiography. In such cases, consideration should be given to the use of a different inspection method.
- Double wall techniques for pipe inspection should be avoided if possible. If such an approach must be used, single image techniques are to be preferred over double image.
- The exact weld geometry, e.g. weld preparation angles, may be unknown. In such cases, multiple shots may be needed if highly reliable results are required.

4.3 Component Material

The material from which the component to be tested is made is crucial in determining the radiographic procedure. While the various types of steel in common industrial use vary little in their attenuation of X- or γ-rays, other materials can show major differences, not only from steel but also from other alloys of the same material. This means that radiography of materials other than steel must be carefully designed, taking account of the properties of the specific material. Factors such as source type, film and source distances and the nature of any IQI used must all reflect the radiographic properties of the material under test.

Recommendations

- Radiographic procedures must be designed taking account of the radiographic properties of the material under test.

4.4 Surface Condition, Weld Caps and Changes in Section

The influence of surface condition on radiography is through sharp irregularities and changes in section. These may produce images which can be misinterpreted as defects or can obscure them. Consequently the surface through which the examination takes place should be free from irregularities such as weld ripples, grinding marks etc. Weld surfaces should be smooth and any change in section should be gradual. Welds may be examined in the as-welded condition by agreement between the contracting parties. It should be accepted that, if this is done, sensitivity to defects will be lower than if the weld had been dressed. If it is necessary to inspect without improving an as-welded surface, various expedients are available to minimise the effects and are listed in the standards [Refs 5, 9].

Recommendations

- For maximum sensitivity to defects, the surface through which radiography is carried out should be free of sharp irregularities or changes in section.

4.5 Equipment & Consumables

The application of radiography, the associated film processing, film viewing and interpretation require the use of many pieces of equipment and chemicals. Such items are listed below and require suitable control, calibration and maintenance to ensure that they are able to perform as required during an inspection.

All inspection, measuring and testing equipment shall be calibrated and maintained in accordance with and compliance to national (or international) standards following the principles and system embodied in British Standard BS EN ISO 10012:2003 [Ref. 14]. All calibration and maintenance of the instruments must be substantiated by documentary proof (reports, data sheets or certificates) confirming the date, accuracy and condition which prevailed at the time when the results were validated and referenced to the national (or international) standard applied. The certificates shall reference the estimate of the uncertainty of measurement for the particular calibration carried out. Whenever a piece of equipment is subject to control tests or calibration, then where possible a small label shall be affixed to the machine or instrument indicating the calibration date and calibration due date.

The NDT vendor should have adequate organisational arrangements, procedures and records for the calibration of equipment and an individual nominated to be responsible for ensuring the proper control of all tests in compliance with national (or international) standards and for any other equipment tests in accordance with any client ‘s specific requirement.

Typical equipment and chemicals requiring control, calibration and maintenance include:

- Temperature measurement (Thermometers) for processing chemicals
- Densitometers
- Image Quality Indicators (IQI's)
- Light meters
- Isotope containers
- X-Ray sets and warning systems
- Radiation monitors and personal audible alarms
- Film processor
- Radiographic illuminations
- Radiographic and photographic film
- Radiographic developer
- Fixer, hardener, wetting agent and stop bath acid
- Incident Emergency Recovery Kit

Recommendations

- NDT vendors performing radiography should be able to provide evidence of control and calibration of chemicals and equipment respectively.

4.6 Operator Performance

Requirements for radiographic operators can be divided into those which apply to the radiographer producing the radiographs and those which apply to the radiographic interpreter. So far as the former is concerned, it is obviously necessary to provide sufficient time for the planning and the application of the inspection. This is vital for safety reasons as well as the quality of the inspection. One of the commonest causes of unsafe practices is time pressure and this issue is discussed again below and, at more length in Section 6 which deals specifically with radiographic safety. All teams carrying out site radiography should include a Level II qualified through a recognised certification scheme such as those complying with BS EN 473 [Ref. 7] and a Company approved Radiation Protection Supervisor (RPS). Apart from certificating the ability of the operator to produce satisfactory radiographs, award of such a certificate involves a knowledge of radiation safety issues.

Radiographic interpreters should also be qualified through a recognised scheme such as those complying with BS EN 473. These certificate the ability of the interpreter to draw conclusions from radiographs about the defects present in the inspected component. Different categories of qualification are available for interpretation of radiographs in different materials and obtained using different techniques. Clearly, those carrying out radiographic interpretation should have the appropriate qualification for the inspection in question. A requirement of the certification is that the interpreter should have an annual eye test to ensure his/her vision continues to meet the necessary standard. Interpreter certification may form part of that awarded to the radiographer, allowing him/her to perform both activities.

Recommendations

- All teams involved in carrying out radiography should include a Level II who is qualified to through a recognised certification scheme such as those complying with BS EN 473. Also, one member of the team should be an approved RPS.

- Radiographic interpreters should have the appropriate category of qualification for the inspection in question.
- Adequate time, facilities and access to the plant should be available to plan and carry out radiography.
- For manufacturing inspection of components in categories 3 and 4 as defined in the Pressure Equipment Directive, where the requirements are most onerous, (to comply with requirements of the PED, all inspectors must be qualified to the satisfaction of the Third Party Body. N.B. Equipment is categorised according to maximum allowable pressure, their volume or their nominal size, as appropriate, and the group of fluids for which they are intended. For details see Ref. 13.

4.7 Organisation and Procurement of NDT

It is crucial, if the radiography is to be effective, that the requirements are defined as discussed in 4.1 and 4.2 above. The inspection method must be chosen and the procedure must then be written taking these requirements into account along with the other geometry and material requirements discussed above. Level 3 inspectors have a role in ensuring that this activity is carried out correctly (see Appendix 3). It is important that the contractual arrangements define the relative responsibilities of purchaser and vendor.

Industrial radiography involves the use of intense, potentially dangerous sources of radiation. It is essential that work is planned and carried out in a way which minimises radiation exposure to all personnel. Careful planning in advance and a system of work that recognises the dangers and seeks to minimise them is crucial. Adequate time in advance of the inspection and to carry it out are both prerequisites to safe radiography on-site. These issues are discussed in more detail in Section 6 which deals specifically with safety issues.

As described in the previous section, incentives to complete the maximum amount of inspection in a given time inevitably lead to a deterioration in safety as well as in inspection quality . <u>It is imperative when agreeing contracts to ensure that the NDT vendor is not encouraged to risk safety and quality for speed. In particular, the remuneration of all those involved in inspection activities should not depend on the number of inspections carried out in a given time.</u>

It is also important that organisations contracted to undertake the radiography exercise adequate control over how it is implemented. NDT companies should have a certified quality control system in place relating to the whole of their activities against which they have been audited. These should include aspects such as health, safety and environmental issues, purchase and control of consumables as well as the way the company is organised and the way in which the inspections themselves are controlled. The quality system should specify the role of the Level 3 operator. The recommendations of the present document should be considered in producing and assessing the quality system.

Accreditation schemes for NDT companies are available and can provide reassurance to the purchaser of NDT services that the vendor’s quality system is an appropriate one.

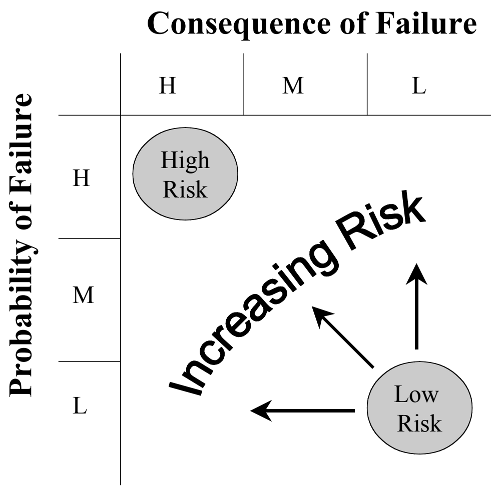
If there is a paramount requirement to establish the performance of a particular radiographic inspection, consideration should be given to the use of formal inspection qualification. The implications of this are discussed in the document on ultrasonic inspection (Ref. 1).

<u>Recommendations</u>

- The contractual responsibilities and technical expectations of purchaser and supplier should be made clear when inspection contracts are placed.
- Radiography service contracts should be framed so that safety and quality are not prejudiced by time or production rate pressures. There should also be no financial incentive to reduce the time taken to unreasonable levels.
- NDT companies should have a certified quality system for controlling the implementation of the NDT, including health, safety and environmental issues. It should be recognised that operators must work within the context of a company which can support their activities and not as individuals. Consequently when employed directly by the purchaser, operators should work within the purchaser's quality system.
- Purchasers of NDT services should consider requiring their suppliers to be suitably accredited or audit the NDT vendor themselves.
- If there is a need to establish the exact performance of a particular inspection, consideration should be given to the use of inspection qualification.

5. INSPECTION IMPROVEMENTS AND COMPONENT RISK

The previous section describes the different measures which can be taken to ensure that radiographic inspections are as effective as possible. It is necessary for those who commission or purchase inspections to determine which of the measures is appropriate to their particular inspection and whether to adopt it. A major factor in determining which additional measures should be used is the role of the inspection and the effectiveness required from it in reducing the risk of component failure. The risk of component failure is determined by a combination of both the consequence and the probability of failure. The consequence relates to the safety or economic effects of the failure. Inspection can only reduce risk by reducing the probability of failure, which , for example, could be related to the likelihood of defects being present in the component that could lead to failure. If the consequence and probability parameters are denoted as high (H), medium (M) or low (L), their combined effects can be indicated on a 3x3 matrix as follows:



Inspection effectiveness is assigned a value of 1 (low), 2 or 3 (high) according to the reduction of probability of failure that it produces in a particular case. To reduce the probability of a component failure from high to low would require a high level of inspection effectiveness, whereas to reduce the probability from medium to low would require a medium level inspection effectiveness.

For example, for a component whose failure consequence is high, inspection should have the potential to reduce the probability of failure to a low level. Therefore, if the probability of failure is high, the inspection effectiveness must be high i.e. 3. However, in practice the precise contribution of NDT must be assessed prior to assigning effectiveness level 3.

Conversely, for a component whose failure consequence is low and whose failure probability is medium or low, inspection has limited ability to reduce risk further and will generally be carried out as part of a routine in-service maintenance programme. The requirements for measures additional to those normally involved in the approach described in Section 2 will be minimal i.e. only a low (1) inspection effectiveness is required.

Using these definitions of inspection effectiveness, Table 1 indicates which of the measures identified in Section 4 it is appropriate to consider for radiographic inspection. In each case it is assumed that there is technical merit in using the additional measure because it would be of benefit to the inspection. What is indicated in the table is whether the additional confidence that would result from adoption of the measure is justified by the effectiveness required of the inspection itself. Inspections where effectiveness 2 or 3 is required have been combined but it would be expected in general that more additional measures would be justified for level 3 than level 2.

6. SAFETY IMPLICATIONS

Industrial Radiography is covered by the Ionising Radiations Regulations 1999 (IRR99) which mostly came into force on 1 January 2000. Information regarding the requirements of the regulations is available from the HSE website: http://www.hse.gov.uk/radiation/ionising/

The web site states that doses for the industrial radiography sector remain higher than other CIDI (Central Index of Dose Information) categories despite targeted action by HSE. In 1998, significantly more industrial radiographers than nuclear industry workers received exposures to ionising radiation greater than 15 millisieverts in a year. The main concerns are that a significant number of NDT contractors fail to adopt routine working practices capable of keeping radiation exposures of employees as low as reasonably practicable: this is the main requirement of the Ionising Radiations Regulations 1999 (IRR99). Incidents occur because of poor job planning (most notably with site radiography); failure to use adequate local source shielding (collimation); operators under unreasonable time pressures or inadequate systems of work. HSE is taking forward a number of initiatives aimed at improving this sector's performance at managing radiation protection. This includes a free information sheet "Industrial radiography - managing radiation risks" Ionising Radiation Protection sheet IRP1.

In addition to the measures described in Section 2.3.1 ("Modern Trends"), one other measure aimed at reducing exposure is a requirement to take items off-site to a shielded enclosure if at all possible. Site radiography is to be undertaken only if removal is not practicable.

As discussed above in sections 4.6 and 4.7, it is vital for safety issues to be given the highest priority when planning and carrying out radiography on site. Adequate time in advance of the inspection is vital to plan the inspection and prepare work plans which recognise the prime importance of safety. Adequate time is also needed when carrying out the inspection to avoid pressure to produce results too quickly and, in so doing, to compromise safety. It is also necessary to limit the time on duty of radiographers to prevent fatigue from affecting safety. These issues are discussed at length in the free information sheet.

In order to ensure that sufficient time is allowed to plan the job, the HSE require on site radiography contractors to give the HSE at least seven days advance notification of work.

Radiation employers will need to appoint and consult a suitable Radiation Protection Advisor (RPA) for advice on complying with the Ionising Radiations Regulations 1999 (IRR99). IRR99 specifies particular matters on which radiation employers should seek advice from a suitable RPA. The Approved Code of Practice in support of IRR99 gives further guidance on this topic. Radiation employers need to check that the RPA selected meets the criteria of competence in the HSE Statement on radiation protection advisers and has the relevant experience to make them suitable to provide the advice needed.

The radiography contractor must appoint a Radiation Protection Supervisor who has the duty to see that the written local rules outlining the systems for work are followed. The HSE also provide an information sheet on Radiation Protection Supervisors on the HSE website.

7. HEALTH IMPLICATIONS

The application of radiography requires the use of a range of chemicals for film processing etc. These chemicals may pose a risk to health for the operators handling them if these risks are not properly controlled, therefore appropriate precautions should be taken. The Control of Substances Hazardous to Health Regulations (COSHH) impose duties on employers to assess the risks to health arising from exposure to hazardous substances, and to ensure that exposure to these substances is prevented or, where this is not reasonably practicable, adequately controlled. Information regarding the requirements of the COSHH regulations is available from the HSE website: http://www.hse.gov.uk/coshh/index.htm.

REFERENCES

1. “Best Practice for the Procurement and Conduct of Non-Destructive Testing. Part 1: Manual Ultrasonic Inspection”, HSE Gas and Process Safety Technology Division, November 2000

2. "Best Practice for the Procurement and Conduct Of Non-Destructive Testing. Part 2:Magnetic Particle and Dye Penetrant Inspection”, HSE Gas And Process Safety Technology Division, November 2001

3. "The Unreliability of Non-destructive Examinations.", Forli, O & Pettersen, B. 4th European Conference on NDT, London, Sept. 1987 p832

4. "Non Destructive Testing of Thin Plate, Final Report" NIL Report No. NDP 93-40.

5. “Non-destructive examination of welds. Radiographic examination of welded joints”, British Standard BS EN 1435, 1997

6. “The Capabilities and Limitations of NDT. Part 3. Radiographic Methods”. R Halmshaw, The British Institute of NDT, 1988

7. " Qualification and Certification of Non-Destructive Personnel – General Principles”, British Standard BS EN 473, 1993

8. “Non-Destructive Testing – Qualification and Certification of Personnel”, International Standard ISO 9712, 1992

9. "Non-Destructive Testing-General Principles for Radiographic Examination of Metallic Materials by X- and Gamma-Rays” British Standard BS EN 444, 1994

10. " Reliability of Radiography for Detection of Planar Manufacturing Defects in Thick – Section Welds”, A B Wooldridge, R K Chapman, G S Woodcock, I Munns and G Georgiou, Insight, Vol. 39 No 3, March 1997

11. “Programme for the Assessment of NDT in Industry (PANI)”, B McGrath, AEA Technology, Report No. IVC99/56, 1999

12. “Guide to the Application of Real Time Radiography to Weld Inspection”, British Standard BS 7009, 1988

13. Pressure Equipment Directive. European Council 97/23/EC, 1997

14. “Measurement management systems. Requirements for measurement processes and measuring equipment”, British Standard BS EN ISO 10012:2003

Additional Measure	Reference in Text	Required Inspection Effectiveness 1	Required Inspection Effectiveness 2 and 3
Involvement of Level III Inspector	4.7	Yes	Yes
Use of Defect parameters in Inspection Design	4.1	No	Yes
Geometry and access-specific procedure	4.2	Yes	Yes
Multiple shots to cope with unknown weld geometry	4.2	No	Yes
Material-specific procedure	4.3	Yes	Yes
Smooth component surface without sharp irregularities	4.4	No	Yes
Removal of weld cap	4.4	No	Yes
System for control of materials and calibration of equipment	4.5	Yes	Yes
Good time allowance	4.6	Yes	Yes
Involvement of Level II in the actual inspection	4.6	Yes	Yes
Appropriate qualification for interpreters	4.6	Yes	Yes
Use of Quality system	4.7	Yes	Yes
Accreditation of supplier	4.7	Yes	Yes
Clear contractual responsibilities	4.7	Yes	Yes
Inspection qualification	4.7	No	As required

Table 1 - Measures to be Considered in Relation to Required Inspection Effectiveness for Radiography

***Note**: Inspections where effectiveness 2 or 3 is required have been combined but it would be expected in general that more additional measures would be justified for level 3 than level 2.*

APPENDIX 1 - MEMBERS OF THE DOCUMENT DRAFTING COMMITTEE

Dr M J Whittle	Independent NDT Consultant (Chairman)
Mr H Bainbridge	Principal Specialist Inspector, HSE
Mr P Heyes	Head of Engineering Control, Health & Safety Laboratory
Mr R W Gregory	Senior Engineering Associate, ExxonMobil Engineering Europe Ltd
Mr E Horton	Principal Consultant, BP Amoco Exploration
Mr R F Lyon	Corporate Engineer, Inspection management (NDT), Innogy plc
Dr L Morgan	Senior Principal Engineer, Advantica
Mr S Smalley	Development Engineer, Royal & SunAlliance Engineering
Mr S Hewerdine	NDT & Technical Welding Manager, OIS Ltd
Dr J Rudlin	Principal Consultant, TWI
Mr F Hardie	NDT Group Leader, Mitsui Babcock Ltd
Dr G Georgiou	Representative , British Institute of NDT
Mr M Baborovsky	NDT Engineer, BNFL Magnox Electric plc
Dr B McGrath	Technical Consultant, Inspection Validation Centre, Serco Assurance (Secretary)

APPENDIX 2 - RELEVANT STANDARDS

DATA OBTAINED FROM BSI WEB SITE JANUARY 2005

http://bsonline.techindex.co.uk

(pr) BS EN Number	Progress Status	Title of Standard	Publication Date
BS EN 444:1994	Current	Non-destructive testing. General principles for radiographic examination of metallic materials by X- and gamma-rays	May 1994
BS EN 462-1:1994	Current	Non-destructive testing. Image quality of radiographs. Image quality indicators (wire type). Determination of image quality value	April 1994
BS EN 462-2:1994	Current	Non-destructive testing. Image quality of radiographs. Image quality indicators (step/hole type). Determination of image quality value	August 1994

(pr) BS EN Number	Progress Status	Title of Standard	Publication Date
BS EN 462-3:1997	Current	Non-destructive testing. Image quality of radiographs. Image quality classes for ferrous metals	April 1997
BS EN 462-4:1995	Current	Non-destructive testing. Image quality of radiographs. Experimental evaluation of image quality values and image quality tables	April 1995
BS EN 462-5:1996	Current	Non-destructive testing. Image quality of radiographs. Image quality indicators (duplex wire type), determination of image unsharpness value	November 1996
BS EN 584-1:1995	Current	Non-destructive testing. Industrial radiographic film. Classification of film systems for industrial radiography	May 1995
BS EN 584-2:1997	Current	Non-destructive testing. Industrial radiographic film. Control of film processing by means of reference values	June 1997
BS EN 1330-3:1997	Current	Non-destructive testing. Terminology. Terms used in industrial radiographic testing	September 1997
BS EN 1435:1997	Current	Non-destructive examination of welds. Radiographic examination of welded joints	December 1997
BS 7009:1988	Current, Confirmed	Guide to application of real-time radiography to weld inspection	September 1988 (Confirmed October 2001)

(pr) BS EN Number	Progress Status	Title of Standard	Publication Date
BS EN 12517:1998	Current	Non-destructive examination of welds. Radiographic examination of welded joints. Acceptance levels	June 1998
BS EN 12543-1:1999	Current	Non-destructive testing. Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing. Scanning method	December 1999
BS EN 12543-2:1999	Current	Non-destructive testing. Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing. Pinhole camera radiographic method	December 1999
BS EN 12543-3:1999	Current	Non-destructive testing. Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing. Slit camera radiographic method	December 1999
BS EN 12543-4:1999	Current	Non-destructive testing. Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing. Edge method	December 1999
BS EN 12543-5:1999	Current	Non-destructive testing. Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing. Measurement of the effective focal spot size of mini and micro focus X-ray tubes	December 1999

(pr) BS EN Number	Progress Status	Title of Standard	Publication Date
BS EN 12679:2000	Current	Non-destructive testing. Determination of the size of industrial radiographic sources. Radiographic method	June 2000
BS EN 12681:2003	Current	Founding. Radiographic examination	February 2003
BS EN 13068-1:2000	Current	Non-destructive testing. Radioscopic testing. Quantitative measurement of imaging properties	March 2000
BS EN 13068-2:2000	Current	Non-destructive testing. Radioscopic testing. Check of long term stability of imaging devices	March 2000
BS EN 13068-3:2001	Current	Non-destructive testing. Radioscopic testing. General principles of radioscopic testing of metallic materials by X- and gamma rays	September 2001
BS EN 13100-2:2004	Current	Non destructive testing of welded joints of thermoplastics semi-finished products. X-ray radiographic testing	December 2004
BS EN 14096-1:2003	Current	Non-destructive testing. Qualification of radiographic film digitisation systems. Definitions, quantitative measurements of image quality parameters, standard reference film and qualitative control	May 2003
BS EN 14096-2:2003	Current	Non-destructive testing. Qualification of radiographic film digitisation systems. Minimum requirements	May 2003

(pr) BS EN Number	Progress Status	Title of Standard	Publication Date
BS EN 25580:1992	Current	Specification for minimum requirements for industrial radiographic illuminators for non-destructive testing	June 1992

APPENDIX 3 - LEVELS OF PCN CERTIFICATION AVAILABLE

(This text is taken from the PCN document " General Requirements for Qualification and PCN Certification of NDT Personnel" (http://www.bindt.org/Mk1Site/PCN.pdfs/PCNGEN.pdf). The range and scope of PCN certification available at each level is defined in the relevant appendix to these general requirements. Radiographic Interpretation on its own is a single qualification and is not offered at the different levels.

1. PCN Level 1
PCN Level 1 personnel are qualified to carry out NDT operations according to written instructions under the supervision of PCN Level 2 or PCN Level 3 personnel. PCN Level 1 certificated personnel have demonstrated the competence to:
- Set up equipment;
- Carry out the test;
- Record and classify the results in terms of written criteria;
- Report the results.

PCN Level 1 personnel have not demonstrated competence in the choice of test method or technique to be used, nor for the assessment, characterisation or interpretation of test results.

2. PCN Level 2
PCN Level 2 personnel have demonstrated competence to perform and supervise non-destructive testing according to established or recognised procedures. Within the scope of the competence defined on the certificate, PCN level 2 personnel may be authorised to:
- Select the NDT technique for the test method to be used;
- ISO 9712 does not include the above as a level 2 competence; the PCN Scheme therefore defaults to compliance with EN 473.
- Define the limitations of application of the testing method;
- Translate NDT standards and specifications into NDT instructions;
- Set up and verify equipment settings;
- Perform and supervise tests;
- Interpret and evaluate results according to applicable standards, codes or specifications;
- Prepare written NDT instructions;
- Carry out and to supervise all PCN Level 1 duties;
- Provide guidance for personnel at or below PCN Level 2, and
- Organise and report the results of non-destructive tests.

3. PCN Level 3

3.1 PCN Level 3 personnel are qualified to direct any NDT operation for which they are certificated and:

- Assume full responsibility for a test facility or examination centre and staff;
- Establish and validate NDT instructions and procedures;
- Interpret codes, standards, specifications and procedures;
- Designate the particular test methods, techniques and procedures to be used;
- Within the scope and limitations of any certification held, carry out all PCN Level 1 and Level 2 duties, and
- Supervise trainees and PCN Level 1 and 2 personnel.

3.2 PCN Level 3 personnel have demonstrated:

- A competence to interpret and evaluate test results in terms of existing codes, standards and specifications;
- Possession of the required level of knowledge in applicable materials, fabrication and product technology sufficient to enable the selection of NDT methods and techniques, and to assist in the establishment of test criteria where none are otherwise available;
- A general familiarity with other NDT methods;
- The ability to guide personnel below PCN Level 3.

3.3 PCN Level 3 certificated personnel may be authorised to carry out, manage and supervise PCN qualification examinations on behalf of the British Institute of NDT. Where PCN Level 3 duties regularly require the individual to apply routine NDT by a method or methods, the British Institute of NDT strongly recommends that this person should hold and maintain PCN Level 2 certification in those methods.