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Guidelines on Training, Examination and Certification in Digital Industrial Radiology Testing (RT-D)

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GUIDELINES ON TRAINING, EXAMINATION AND CERTIFICATION IN DIGITAL INDUSTRIAL RADIOLOGY TESTING (RT-D)

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

TRAINING COURSE SERIES No. 60

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INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The IAEA promotes industrial applications of non-destructive testing (NDT) technologies. NDT methods are primarily used for the detection, location and sizing of surface and internal defects in, for example, welds, castings, forging, composite materials and concrete. Various NDT methods are also used in the preventive maintenance of nuclear power plants, aircraft and bridges. Thus, NDT technology contributes significantly to the improvement of the quality of industrial products and the integrity of equipment and plants.

The introduction of powerful computers and reliable imaging technology has had significant impact on traditional, nuclear based NDT methods. During the introduction phase in digital industrial radiography (DIR), the digitization of films provided economy of storage, efficiency of communication and accuracy of dimensional measurement. NDT laboratories are progressing rapidly with the digitalization of NDT data. New radiologic imaging techniques in DIR, using image intensifier systems, computed radiography with phosphor imaging plates and digital detector arrays, have increased the capacity for visualization of defects and have revealed new potential for accurate evaluation and measurement.

The development of DIR has been of continuing interest to the IAEA and national NDT societies in recent years. This has led to the formation of projects on the development and application of advanced industrial radiography and tomography techniques under the IAEA Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology.

This publication is intended to provide resource material to support vocational training to NDT radiographers on digital industrial radiography and to help NDT training centres and certification bodies in Member States to establish their own courses, curricula and certification systems in this technology.

The IAEA expresses its appreciation to U. Ewert (Germany) for the preparation of this publication. The IAEA officers responsible for this publication were J.H. Jin and P. Brisset of the Division of Physical and Chemical Sciences.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. SIGNIFICANCE AND USE

The need for training in Digital Radiographic Testing (RT-D) came to the attention of the IAEA during an expert meeting in 1996 and the first training courses were conducted in 2000.

The German Society for Non-Destructive Testing NDT, previously, had initiated a training course on digital radioscopy (RT-S) in 1994 (level 1) followed by a level 2 training course in 1996 (~ 520 certificates altogether, 2012).

RT-D training was proposed as a new method in EN 473 in 2008. The proposal was modified later and it was finally decided to split the RT training into RT-F and RT-D (RT-Film and RT-Digital) as two major techniques, instead of having two independent methods. After ISO 9712:2008 [1], with acceptance of EN ISO 9712 in 2012 [2], EN 473 [3] and prEN473 [4] were withdrawn and no further changes were implemented. The amendment, as discussed for EN 473 revision, should be considered for the next revision of ISO 9712 after 2012.

This guideline refers to, and considers differences to the IAEA Training Guideline in Non-Destructive Testing Techniques (TECDOC-628/Rev.2) [5], the ISO 9712:2005 [1], ISO 9712:2012 [2] and EN473:2008 [3].

Since the RT-D training has to cover different digital techniques, the following recommendations were submitted to CEN TC 138 recently:

- Digital Radiographic Testing (RT-D) consists of the following digital techniques:

    - Film digitization;
    - Image processing;
    - Computed radiography with phosphor imaging plates;
    - Radiography with digital detector arrays (DDA);
    - Radioscopy (also known under real time radiography);
    - Computed tomography.

- The classical ‘Radiographic Technique’ is the synonym for film radiographic testing (RT-F)
- Since RT-F has been developed over a period of > 100 years it has been regulated by standards in an excellent manner. The description of Film RT and the quality of radiographs as well as the evaluation of the films are the basis for national and international contracting in a variety of industries.
- It can be observed, that the NDT community spends a lot of effort for film replacement by the digital techniques. The image quality and the procedures for digital RT (RT-D) are significantly different from RT-F. Industries and authorities claim that they do not have the proof yet, that the Digital Techniques and the evaluations of the digital radiographs are equivalent to RT-F results due to missing training and standards. Standards for digital radiology have been finalized since 2005 for CR in ASTM and CEN, and for DDA’s in ASTM in 2010. ASME BPVC Section V considered in 2008 the new major digital RT-D techniques. ISO 17636-2 was published in 2013 for “NDT of welds — Radiographic testing — Part 2: X and gamma ray techniques with digital detectors”.

- Specialized training is required in RT-D because significant differences between RT-D and RT-F exist:

    - Knowledge in digital image processing is required in RT-D
    - Noise sources in RT-D need to be understood
    - Contrast to noise ratio (CNR) and signal to noise ratio (SNR) determine the image quality in RT-D instead of density and contrast. This is a significant difference to film radiography.
    - Optimal X-ray energies are different for different RT-D techniques and significantly different to RT-F
    - Most digital detectors have limited sharpness. This requires to be compensated by better CNR
    - RT-D provides more and more accurate measurement tools than RT-F.
    - Many RT-D techniques need geometric magnification, which has to be trained.

- New standards are under development to guarantee that RT-D provides the required quality and the equivalent or better evaluation results (see list of new standards in 5.4). The application of the new RT-D standards requires more skills than are required for RT-F.
- In certain industrial sectors, e.g. automobile and fine casting industries, NDT personnel does not need prior RT-F training and RT-F certification, since film will not be used in radioscopic applications using fluoroscopes, intensifiers or DDA's. RT-D technicians in such industries, therefore, need training in RT-D only. As such, a full training course is required and conducted independently of RT-F training.
- Since a basic knowledge on radiography is essential, RT-F certified personnel can be trained in RT-D with 50% of the required training hours.
- In ISO 9712, RT-D should be also included as a RT technique (see below) since it is significantly different from RT-F.
- Currently in Germany approx. 1400 NDT-technicians are already certified in accordance to EN 473 in digital radiology.

This guideline provides recommendations and requirements for the development of a complete training program for the radiographic technique RT-D in three levels. It also considers the different requirements of industrial sectors as, e.g. fine casting inspection under serial production conditions (RT-S training) and film replacement for training of RT-F certified personnel. Finally, three training modules will be defined for RT-D training, which may be selected from training organizations in agreement with the requirements of the national NDT related industries. The training on RT-D is a specialization for professional radiographers.

Radiation safety is a very important aspect of industrial radiography, regardless of the technique used to produce the image (film or digital). It should be part of the training of any radiographer, as stated in TECDOC 628/Rev 2 [5] and ISO9712-2012 [2]. It is therefore not addressed in these Guidelines.

2. INTRODUCTION TO DIGITAL INDUSTRIAL RADIOLOGY

2.1. THE METHOD OF RADIOGRAPHIC TESTING (RT)

Non-destructive testing (NDT) methods, including radiography, are largely used for detection, location and sizing of surface and internal defects (in welds, castings, forging, composite materials, concrete and many more). The RT method is based on the generation of X or gamma rays, which pass through a test specimen. On the opposite side the attenuated radiation is detected and the intensity distribution is stored in a radiological image (see Fig. 1).

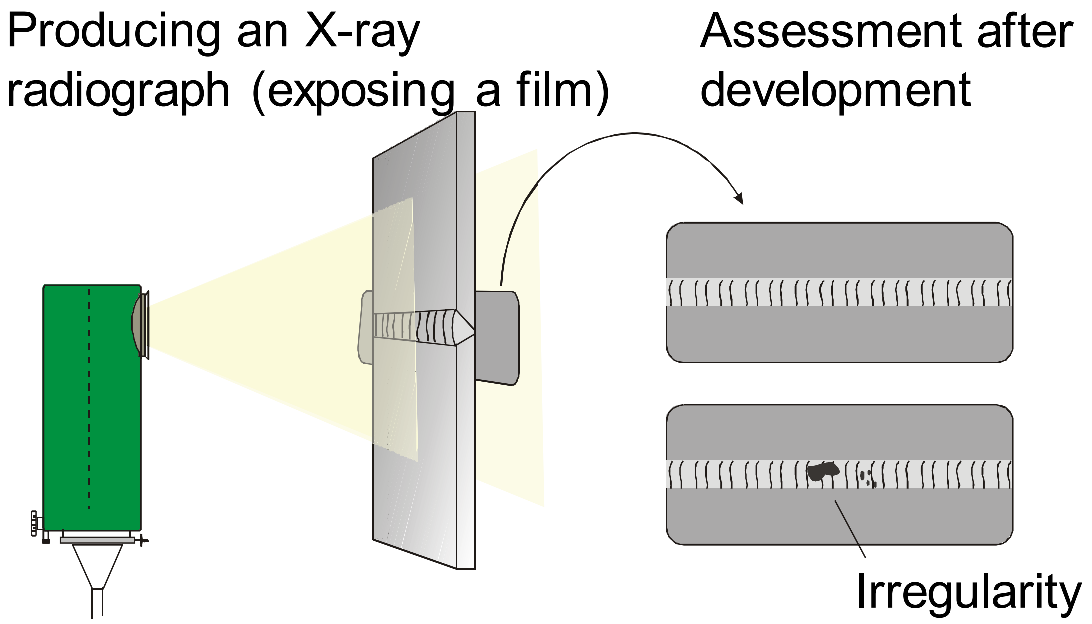

FIG.1. Typical set-up for radiographic inspection with film and assessment.

RT still represents the largest NDT technique in the market. At present, still worldwide increasing amount of industrial NDT testing is carried out using radiographic film, sandwiched between lead intensifying screens, as a detector. Upcoming digital detectors start to substitute film applications in analogy to digital photography. RT is largely accepted in industry, due to the following reasons:

- Technically superior in defect detection ability for internal defects in many situations, e.g. inspection of complicated shapes and where contactless techniques are required.
- Radiographic testing is the only option for the majority of in-line factory production line testing, e.g. in-line testing of castings, electronic components e.g. PCBs and food products. Here, any interruption to the process is unacceptable and the only testing techniques, which can satisfy these constraint is radiographic/radioscopic testing.
- Can detect defects in structures where direct access is not possible e.g. pipelines and other structures covered with thick paint, insulation or having a rough surface finish. Here, other NDT techniques require considerable preparation time.
- Good defect detection ability in multi-layered structures, austenitic steels and composites, where other NDT techniques such as Ultrasonic Testing (UT) cannot be used due to attenuation and scattering problems.
- Results of inspections are easy to interpret.

The ability of this source-specimen-detector system to detect flaws, termed usually as sensitivity of flaw detection, depends upon a number of factors. Most of these can be attributed to all the three components of the system, namely, the source, the specimen and the film. These factors can be briefly listed as:

- Type of specimen, its geometry, shape, thickness, physical density, type, location and orientation of defects with respect to the direction of the beam;
- Energy of radiation and source size;
- Scattered radiation, filters if used, source-to-film and specimen-to-film distances;
- Type of detector or film (its definition, contrast and structure noise), processing, viewing conditions, screens;
- Operator's eye sight, qualification, skill and experience.

Sensitivity is a general term used to describe the ability of a radiograph (digital or analog) to show details in the image. It is a reference to the amount of information or detail in the image. For example, if very small flaws can be seen in the radiograph, it is said to have high or good sensitivity. Radiographic sensitivity depends on image contrast, definition and image noise. Image noise is commonly described as graininess in film radiography.

Practically sensitivity is determined through the use of image quality indicators (IQI) of which there are several kinds. These include the wire type, step wedge type, plate-and-hole type, and step-and-hole type. In the wire type there are two classifications, single wire type and the duplex or wire pair type. The IQI, in principle should be of the same material as the test specimen, except the duplex wire type. It is placed on the surface of the test specimen facing the source and then the exposure is made. The minimum diameter of the wire visible on the radiograph is noted. The sensitivity is then calculated and comes out in percentages, for example, 1%, 2%, 4% etc., the lower the value the better the sensitivity of flaw detection.

2.2. LIMITATIONS OF CONVENTIONAL FILM RT METHOD (RT-F)

Film radiography provides high-resolution images, but it suffers also from several major disadvantages, including:

- low efficiency leads to longer exposure times;
- radiographic films are not reusable;
- requires considerable film developing facilities;
- requires considerable time to develop film and interpret results;
- exposes workers to hazardous chemicals during film development;
- storage and retrieval costs for radiographs after inspection;
- deterioration of X ray film;
- subjectivity in analyzing radiographs

2.3. FILM DIGITIZATION

Film digitization is not a filmless technology, but allows using all means of computer processing also with classical film exposures.

There are several types of film digitization systems such as Point by Point Digitization, Line by Line Digitization and Array Digitization. The most commonly used is the point by point digitization, where the film is moved in front of a collection tube. A laser beam with a fixed diameter passes the film. The diffuse transmitted light through the film is integrated by the collection tube and registered by a photo multiplier (PMT) on top of the collection tube. During the scan the folding mirror moves the laser beam along a horizontal line on the film. The resulting voltage at the photo multiplier is proportional to the light intensity behind the film. After amplification a digitization yields grey values that are proportional to the optical density of the film.

Because of a spatial resolution of better than 10 µm and optical density of up to 5 high end digitization yields several new possibilities for conventional radiographic testing. These include, for example, digital film archiving, quantitative evaluation, image processing, automatic image evaluation, remote image transfer and production of reference catalogues for flaw evaluation.

2.4. DEVELOPMENT OF DIR - DIFFERENCES AND SIMILARITIES BETWEEN DIGITAL RADIOLOGY (RT-D) AND FILM RADIOGRAPHY (RT-F)

Wilhelm Conrad Röntgen discovered the X-rays in 1895, which are also known as “Röntgenstrahlen”. He used a film for visualization of parts of the human body and technical objects already in the same year. Fig. 2 shows the development of alternative detectors to film during the last 50 years. A driving force was, except economic aspects, also the reduction of dose for medical radiology. The most important development for radioscopy was the image intensifier and for film replacement the development of Computed Radiography with imaging plates and Digital Detector Arrays.

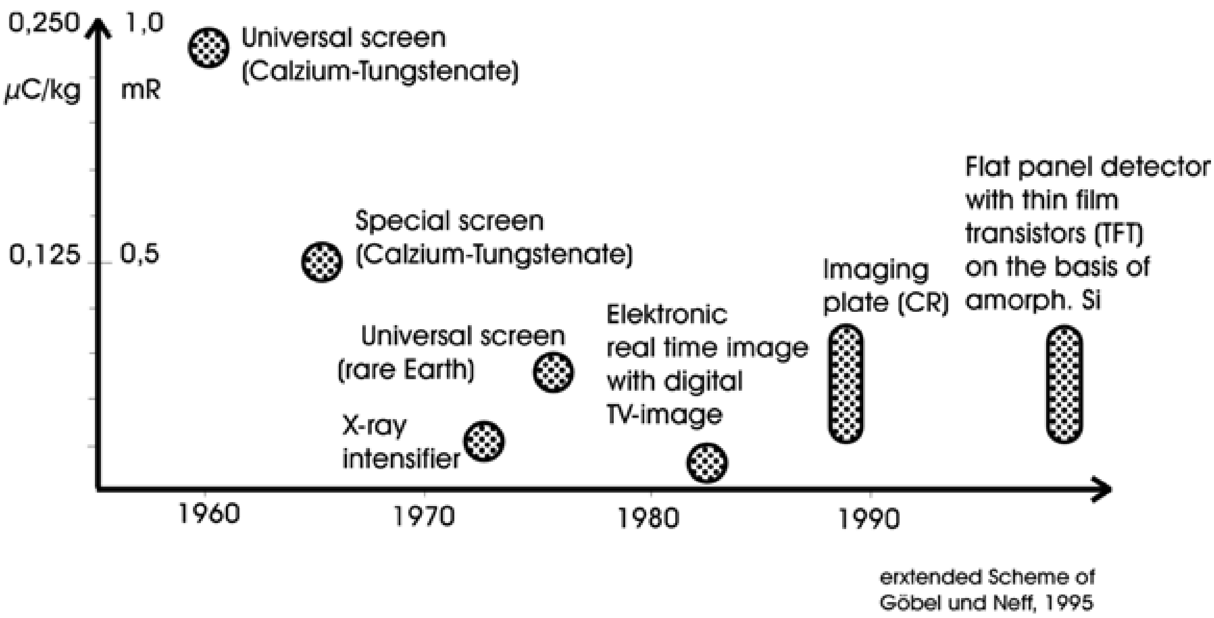

FIG. 2. Development of radiological detectors of the past 50 years.

Differences and similarities have to be considered if film radiography is replaced by digital radiography:

- The digital industrial radiography (DIR) procedure is significantly different from the film radiography procedure.
- But: The optical impression of digital radiographic images is not different from film images in its structure (if no digital image processing is applied, except brightness and contrast control).
- RT-trained personal can interpret digital images in analogy to film.
- Digital images need a computer and monitor for presentation and may be altered by specialized image processing.
- A basic training in image processing is essential to avoid miss interpretation.

- Quantitative assessment of flaw sizes is improved by digital measuring tools but the results may differ from those ones of film interpretation.
- New electronic reference catalogues may support correct image assessment.

2.5. COMPUTED RADIOGRAPHY WITH PHOSPHOR IMAGING PLATES

Direct digitising systems accelerate the application of intelligent procedures to facilitate and enhance image interpretation. Since about 10 years imaging plate systems are available for NDT and this can be used as filmless radiography technique, also known as computed radiography (CR) with phosphor imaging plates (IP).

In the 1980s a step forward was made first in medicine by using imaging plates which are able to store the image, eliminating the film and the required processing chemicals and giving birth to Computed Radiography.

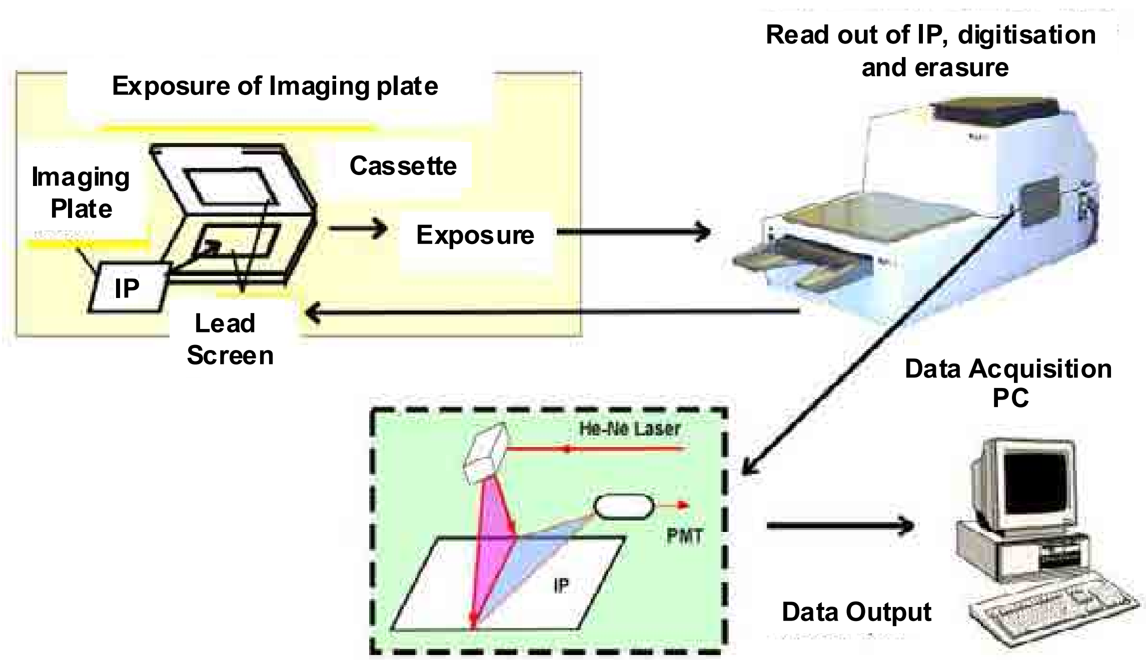

FIG. 3. Principle of Computed Radiography with imaging plates and cycle of exposure, scanning and erasure.

An IP consists of a flexible polymer support coated with a sensitive layer. On top it is covered with a thin transparent protective layer. The sensitive layer of most common systems consists of a mixture of BaFBr crystallites doped with Europium and a binder. X-rays or gamma ray quanta result in activation of F-centers in the crystallites, which result in the emission of blue light photons on stimulation with red light photons through a process known as photo stimulated luminescence PSL (see Fig. 3). After X-ray exposure imaging plates have to be scanned by a laser scanner to obtain a digital radiographic image. Finally, the residual information stored in the F-centres can be erased by exposure with bright white light and the IP can be reused up to 1000 times, if carefully handled. Different imaging plate systems are commercially available with different thickness, unsharpness and sensitivity. Guidelines and standards which define the good workmanship criteria for the new digital detectors were development and are again under revision to avoid a loss of information and reduced probability of flaw detection, which may occur by adoption of the medical systems without adaptation to NDT requirements.

Imaging plates are used as film replacement, since they provide a similar image quality than film and require a separated exposure for generation of the virtual image. The final generation of the image is performed by a digital laser scanner, which reads the digital radiographic image from the exposed IP.

2.6. DIGITAL RADIOLOGY WITH DIGITAL DETECTOR ARRAYS (DDAS)

The action principle of digital detector arrays is based on the conversion of the incoming X-rays into electrical charges that are electronically readable. In case of the indirect conversion methods, matrices of photo-diodes are employed which are able to convert the radiation (either X-ray or light) into electrical charges. In each photo diode, the charges are integrated over a given time period before they are readout electronically for each single pixel followed by graphic presentation via a suitable data acquisition (see Fig. 4). Each photo diode is linked to an adjacent TFT switch (TFT = thin film transistor – see also laptop displays) that activates the readout process of the accumulated charges at a given time.

The intrinsic photon detection in photo diodes works fine for light photons and X-ray photons up to 20 keV. Above that energy the absorption rate caused by the thin photo diode layer is too low for effective image generation.

For higher X-ray energies the indirect detection is used and is based on a scintillation screen as used in a fluoroscope, but here in direct contact to the photo diode matrix for light detection (see Fig. 4). In this way nearly all light photons leaving the scintillator screen towards the photo diodes are collected by the photo diodes directly touching the screen (see Fig. 5 a). All losses connected with light imaging by a mirror and lens, as used in fluoroscopes, are omitted. As requirement, the photo diode layer should not be degraded by X-ray radiation and the light detection should not be degraded by the penetrating X-ray photons. Because CCD elements are very sensitive to X-rays and cannot be used in direct contact to the scintillator, photo diodes made on CMOS or amorphous Silicon panels are used for light detection.

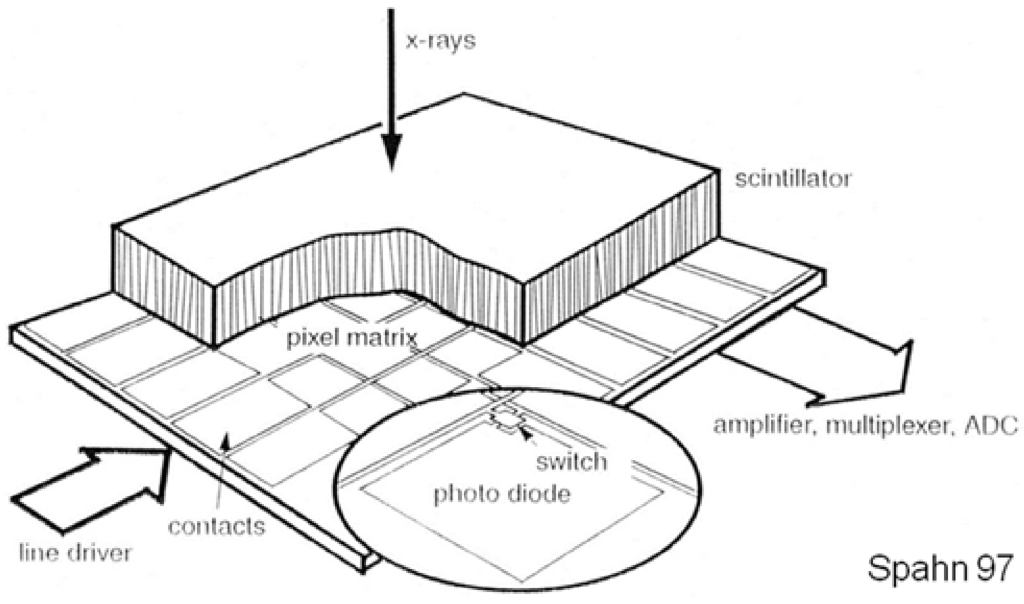

FIG. 4. Construction scheme of an indirect converting digital detector array.

X-rays (or gamma rays) first strike the scintillation layer, then this layer emits photons in the visible spectrum (see Fig. 5 a). These photons are picked up by the underlying amorphous-Si photo-diode array, which converts them to an electric charge. This charge is then converted into digital grey values for each pixel.

The scintillation layer is commonly composed of either cesium iodide or gadolinium oxysulfide. This selection and the optimum scintillator thickness depend on the required image unsharpness and used radiation energies.

Another way to record information regarding detection of electromagnetic waves is direct imaging with photo conductors, using for instance, the amorphous selenium technology or the crystalline CdTe technology. X-rays (or gamma rays) strike a photo conductor made of amorphous-Se or CdTe, which converts them directly into electric charge that's further converted to a digital grey value for each pixel. Pixelised metal contacts (pixel sizes down to 70 µm are available) and ball grid arrays are used to contact the photoconduction layer to the underlying CMOS or amorphous-Si readout-electronics (see Fig 5. b).

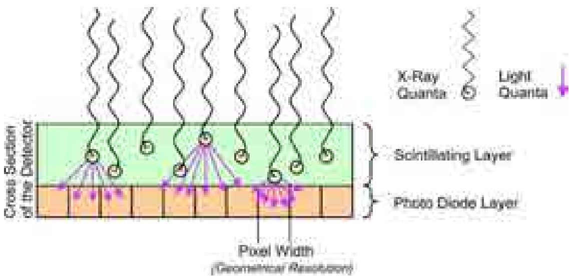

FIG.5a. Working scheme of an indirect converting DDA.

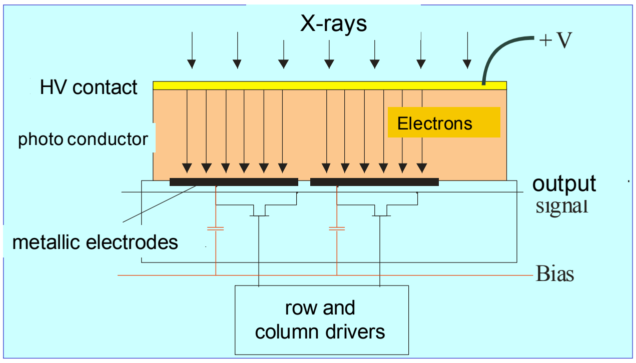

FIG. 5b. Working scheme of a direct converting DDA.

2.7. ADVANTAGES OF DIGITAL RADIOGRAPHIC SYSTEMS

DIR has the following benefits:

- radiation dosage and exposures are reduced resulting in less risk to the operator and less disruption to other operations;
- reduces radiographic inspection time, and improves productivity;
- eliminates chemicals, chemicals disposal and chemical storage costs;
- digital radiographs are not degradable;
- is easily customized for field radiography in a portable package;
- digitization allows radiographic data to be analyzed using imaging and defect detection algorithms;
- storage costs are minimized as all images are stored on hard discs or optical media like CD-ROMs or DVD-RAMs. Images can also be accessed via network and even emailed to experts for real time verification;
- reusable imaging plates mean that savings can be generated as one plate can be used many times;
- significant cost savings due to use of DIR systems have been reported from industry.

2.8. COMPUTED TOMOGRAPHY (CT)

Computed Tomography uses measurements of X-ray transmission from many angles completely encircling the test specimen to compute the relative X-ray linear attenuation coefficients of small volume elements (3D voxels) and presents the data as a cross sectional or 3D attenuation map (see Fig. 6). The clear images of interior planes of an object are achieved without the confusion of superposition of features often found with conventional projection radiography. In the typical source-specimen-film radiographic set up the film is replaced by a one or 2-dimensional array of radiation detectors. For a linear detector array (LDA) the X-ray beam and the detector elements are collimated to a narrow slit and highly aligned to each other to define a slice plane in the specimen. This slit collimation reduces scattered radiation from the inspected object and improves the reconstruction result of this fan-beam CT (important for high X-ray energies with increased X-ray scatter by the inspected object).

Faster inspection times can be realized by using a 2-dimensional image detector (Digital Detector Array) and cone-beam X-ray geometry. In this way a 360° rotation provides projection images of a complete specimen volume. The disadvantage is the missing suppression of scattered radiation generated in the object, which introduces artifacts in the volume reconstruction and reduces the contrast in the projections.

Either the test specimen or the source-detector assembly can be translated and rotated to get views from multiple angles. Especially the 3D Cone-Beam-CT needs computer clusters for image reconstruction of data sets of GBytes per inspected volume.

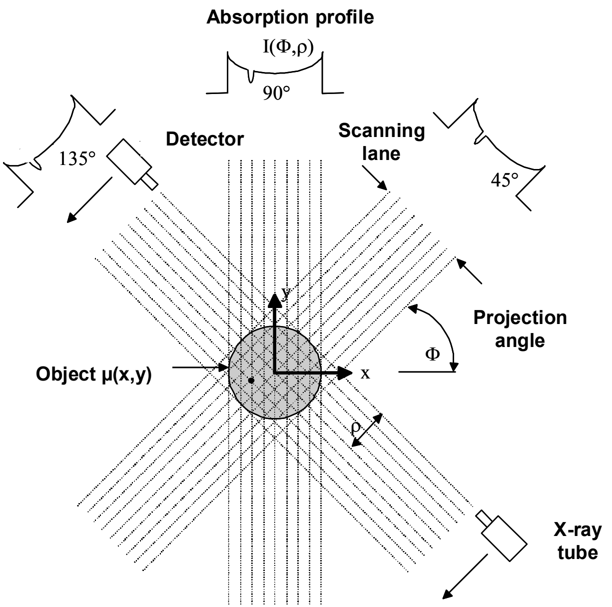

FIG. 6a. Principle of Computed Tomography. Projections are taken from different angles over 360°. The cross section image is calculated by reconstruction software.

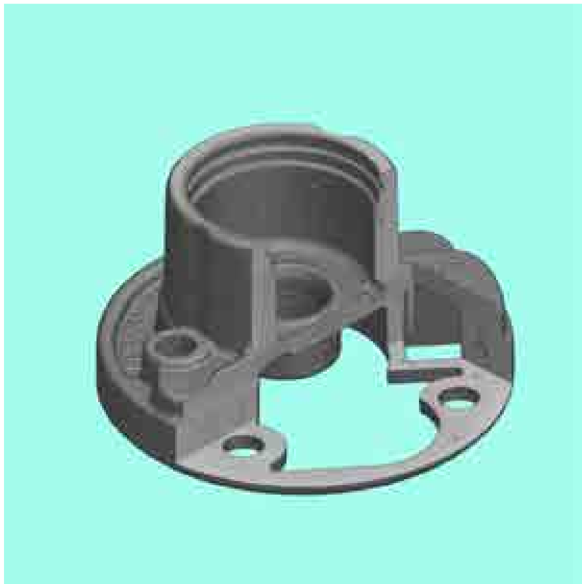

FIG. 6b. Result of a Computed Tomography measurement of a casting with porosities and shrinkage.

2.9. IMAGE QUALITY IN DIGITAL RADIOLOGY

The contrast sensitivity in Digital Industrial Radiology depends on the product of effective attenuation coefficient μ_{eff}, also called specific contrast, and the signal-to-noise ratio (SNR), normalized to the basic spatial resolution SR_b. This applies for Intesifiers, fluoroscopes, CR, DDAs and X-ray film. Fig. 7 illustrates the effect of noise on flaw detection.

The contrast-to-noise ratio (CNR) per wall thickness difference Δt ($CNR^{specific}$), which is the essential parameter for the visibility of flaws and IQIs of a given size, can be calculated from the detector response (SNR) as a function of exposure dose as follows (small flaws only, see Fig. 7):

$$\boldsymbol{CNR/\Delta t = SNR \cdot \mu_{eff}} \qquad (1)$$

The perception threshold (PT) for the visibility of a hole (visibility of small details) by the human operator (see Fig. 8) on the image display can be formulated as follows [20-23]:

$$\boldsymbol{PT = d_{visible} \cdot CNR} \qquad (2)$$

PT - perception threshold, constant for typical human operator

$d_{visible}$ - hole diameter of the just visible hole in the image

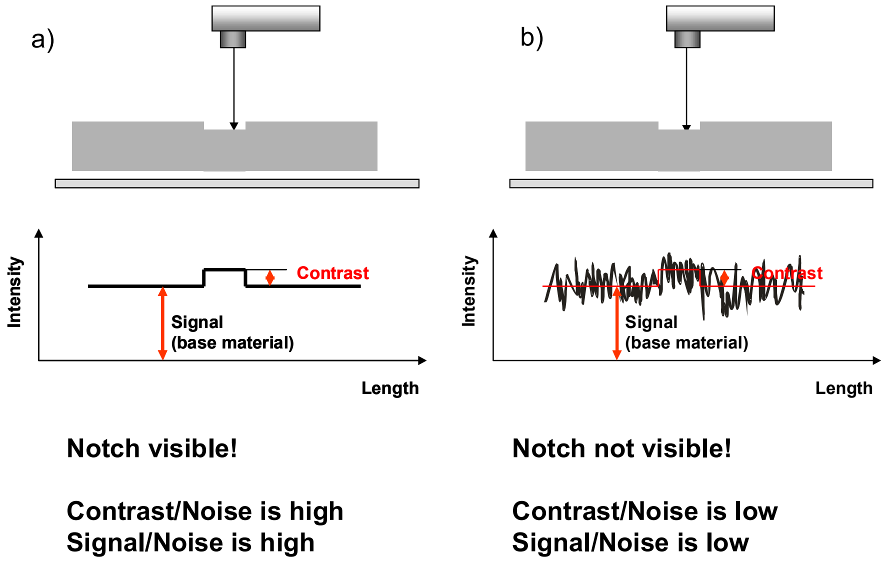

FIG. 7. The influence of noise on the visibility of a notch in radiography.
a) the notch is visible if the noise contribution can be neglected,
b) the notch is not visible if the noise is just higher than the contrast.

Now it is assumed that the hole diameter d is equal to the IQI thickness T = Δt (1T hole with d = T = Δt). The just visible 1T hole diameter and IQI thickness can be calculated from eq. 2 and 3, if PT is known.

Additionally, the number of presented pixel at the monitor has to be considered for correct IQI perception [24]. Since the acquired image size depends on the pixel size and number, the presentation on the image display monitor depends also on the pixel size (one acquired pixel shall be presented at one separate monitor pixel). That means that the real diameter d can be presented with different scaling factors at the monitor. Following the Shannon sampling theorem, the information content of an unsharp image („bandlimited“) is sampled with the size of the unsharpness kernel and therefore, the basic spatial resolution is used instead of the pixel size. In consequence, the effective pixel size SR_b for scaling correction is also considered for calculation of the just visible IQI hole diameter:

$$d_{visible} = PT^* \cdot \sqrt{\frac{SR_b^{image}}{\mu_{eff} \cdot SNR}} = PT^* \cdot \sqrt{1 / CNR_N^{specific}} \tag{3}$$

The basic spatial resolution SR_b corresponds to the effective pixel size (square root of effective pixel area) in a digital image. SR_b can be measured in different ways, but standard committees recommend the use of the duplex wire method due to its simplicity (EN 462-5, ISO 19232-5 and ASTM E 2002). The measurement with the duplex wire IQI provides a total image unsharpness value (u_T) in µm. The basic spatial resolution in a digital image SR_b^{image} is calculated by:

$$SR_b^{image} = u_T / 2 \tag{4}$$

and u_T is calculated by

$$u_{total} = \sqrt{u_{detector}^2 + u_{geometry}^2} \tag{5}$$

$u_{detector}$ is the inherent unsharpness of the detector and $u_{geometry}$ is the geometric unsharpness due to the radiographic set up and focal spot size (see ASTM E 1000).

SR_b or $SR_b^{detector}$ is considered as basic spatial resolution of the detector (effective detector pixel size, magnification = 1), measured with the duplex wire IQI directly on the detector (see also ASTM E 2597, E 2445, E 2446). SR_b^{image} is considered here as the basic spatial image resolution, measured with the duplex wire IQI (ASTM E 2002, EN 462-5) on the source side of the object in the digital image with magnification and unsharpness contributions from the object, which is also a source of scattered radiation.

$SR_b^{detector}$ corresponds typically to the pixel size (pixel limited unsharpness) of direct converting systems (e.g. α-Se-DDA or CdTe-DDA). It is greater than the pixel size (or laser spot size) for CR and larger than the pixel size (photo diode array elements) of DDA's with thicker scintillators. The basic spatial resolution parameter is an essential part of EN 14784, ASTM E 2445, E2446 and E 2597.

The term $\mu_{eff} \cdot SNR/SR_b^{image}$ is considered as normalized specific contrast-to noise ratio ($CNR_N^{specific}$) per mm thickness difference and normalized by SR_b^{image} (see below for definition of SR_b^{image}). PT' depends also on operator and viewing conditions. If the hole diameter is much larger than the unsharpness, the equivalent IQI sensitivity (EPS in %) changes for a given material thickness as follows (see ASTM E 746 and E 1025 for 2T sensitivity):

$$EPS = \frac{PT'}{t_{testplate}} \sqrt{\frac{SR_b^{image}}{\mu_{eff} \cdot SNR}} \qquad (6)$$

with PT' ≈ 200, determined from practical trials for clear visibility of holes on a monitor. The calculated EPS (procedure see ASTM E746 and [24]) by eq. (6) is equivalent to the visually measured EPS values as defined by the procedure of ASTM E 746. It is also equivalent to the requirements and definitions of ASTM E 1742 and E 1025.

Since the gray values of the pixels in the digital images (assuming signal is linear to dose) depend on noise and signal intensity independent of the contrast and brightness processing for image viewing, the SNR has been proposed and accepted as an equivalence value to the optical density and a certain film system in film radiography (EN 14784-1,-2 and ASTM E 2445, E2446).

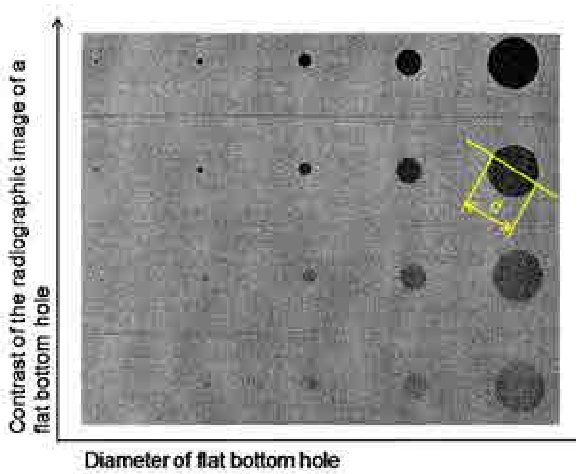

FIG. 8. Grey value image of holes with different contrast, CNR and diameter. The CNR is constant in each line and the diameter is constant in each column. Holes with larger diameter are seen at lower CNR.

▪ PT’ is about 200 for visibility of the 2 T hole of IQIs as defined in ASTM E 1025
▪ EPS by ASTM E 746 with 200 kV, t = 19 mm Fe plate and μ_{eff} = 0.05 mm^{-1}

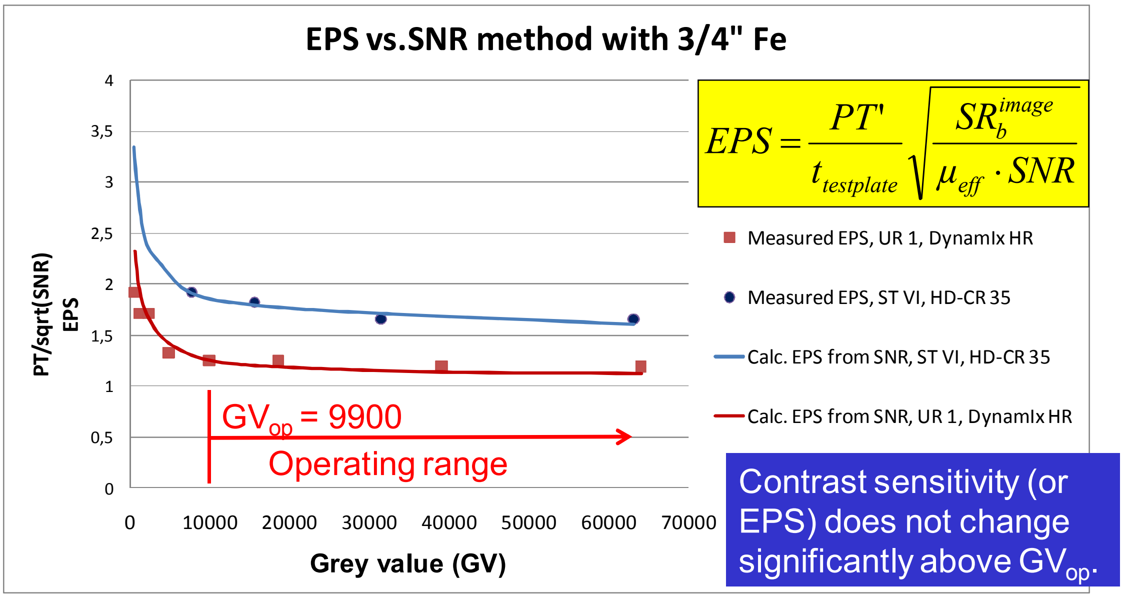

FIG. 9. Determination of operating range and comparison of EPS measurements (200 kV) vs. PT/sqrt(SNR) measurements. The curves fit accurately. The SNR method provides more accurate results. No EPS values were obtained for IP ST VI with Dürr scanner for pixel value PV < 7000, meaning no EPS holes were visible in these radiographs.

Equation (6) was verified with modeling results [23] and experiments. The SNR and the grey values were measured with the software ISee! [11]. Independent operators determined the just visible 1T hole of EN 462-2 IQIs and wire number of EN 462-1 IQIs from modelled images [23]. Wires with 2.5 times smaller diameter than the diameter of the holes were seen with same perception.

Experiments were performed with different CR scanners and imaging plate types with a polished 19 mm (3/4”) Fe-plate at 200 kV to compare visually measured EPS values (strict application of ASTM E 746, 50% method) with calculated data, based on eq. (6). Fig. 9 shows that the visually determined EPS values fit well with the calculated ones (eq. (6)), with PT’ ≈ 200 and μ_{eff} = 0.05 mm^{-1}.

This result allows the determination of EPS detectibility of digital detectors at different energies and for different materials from SNR measurements without object.

EPS curves as shown in Fig. 9 were proposed by the ASTM E07 committee for qualification of the operating range of CR systems. The operator shall provide exposures with a sufficient dose achieving grey values in the range of interest of the digital radiographs greater than GV_{op}. Digital radiographs (CR only) with lover GV than GV_{op} shall be rejected. GV_{op} is determined from the EPS vs. grey value plot as minimum GV of the operating range as shown in Fig.9. The operating range is determined as the GV range which provides stable (constant) EPS readings (see Fig. 9). The exact criterion for determination of GV_{op} is under discussion. In Fig. 9 the operating range was determined as range of EPS variation < 15%.

Different noise sources have to be considered in digital radiography which have its origin in:

- EXPOSURE CONDITIONS: Photon noise, depending on exposure dose (e.g. mA·s or GBq·min). This is the main factor! SNR increases with higher exposure dose.
- Limitation for the maximum achievable SNR:

  - DETECTOR: Structural noise of DDAs and Imaging Plates also called fixed pattern noise (due to variations in pixel to pixel response and inhomogeneities in the phosphor layer).

  - OBJECT:
    - Crystalline structure of material (e.g. nickel based steel, mottling)
    - Surface roughness of test object

The first two noise sources can be influenced by the exposure conditions and detector selection. The achieved Signal-to-Noise Ratio (SNR) of images depends on the exposure dose (low dose application). The SNR increases with the square root of mA·minutes or GBq·minutes, due to the improved photon quantum statistics. The structure noise of films and imaging plates depends on its manufacturing process and can be influenced basically by the selection of the specific detector type (e.g. fine or coarse grained film). Film development and IP scanner properties contribute also to the final noise figure. The structure noise of detectors and all noise sources depending on the object properties determine the maximum achievable SNR and limit, therefore, the image quality independently on the exposure dose (high dose application). Only with DDAs, the structure noise (due to different properties of the detector elements) can be corrected by a calibration procedure, since the characteristic of each element can be measured quite accurately. Figure 10 shows the effect of SNR increase (equivalent to CNR increase) on the visibility of fine flaw indications [13, 14]. The digitized fine grained film provides a SNR of 265 in the base material region. The DDA image was measured with a SNR of about 1500 and magnification of 3.5. It shows significantly finer flaw indications.

Compensation Principle I:

Compensation of reduced contrast (μ_{eff}) by increased signal-to-noise ratio (SNR)

In film radiography, it is well understood that the image quality increases if the tube voltage is reduced. In DIR, it can also be observed that the image quality increases in a certain range if the tube voltage is increased. The higher photon flow (X-ray intensity behind object) increases the SNR in the detected image faster than the reduction of the contrast by the decreased transmission contrast (also known as specific contrast or effective attenuation coefficient μ_{eff}). This effect depends on the ratio of attenuation decrease to SNR increase (see also eq. 1) since the product of SNR and μ_{eff} controls the contrast sensitivity in the digital radiograph. The effect has been observed if DDAs are used for film replacement. Well calibrated DDAs can be exposed typically at higher tube voltages than films. However, too high tube voltage may even reduce the attenuation faster than the SNR increases. The maximum achievable SNR is the limiting parameter for the described compensation. It depends on the detector efficiency and the detector calibration of DDAs or the structure noise of imaging plates. It also depends on the noise of the material's structure and the material roughness. Therefore, the compensation by increase of the tube voltage is restricted depending on the detector and material properties and especially on the maximum achievable SNR in the radiograph.

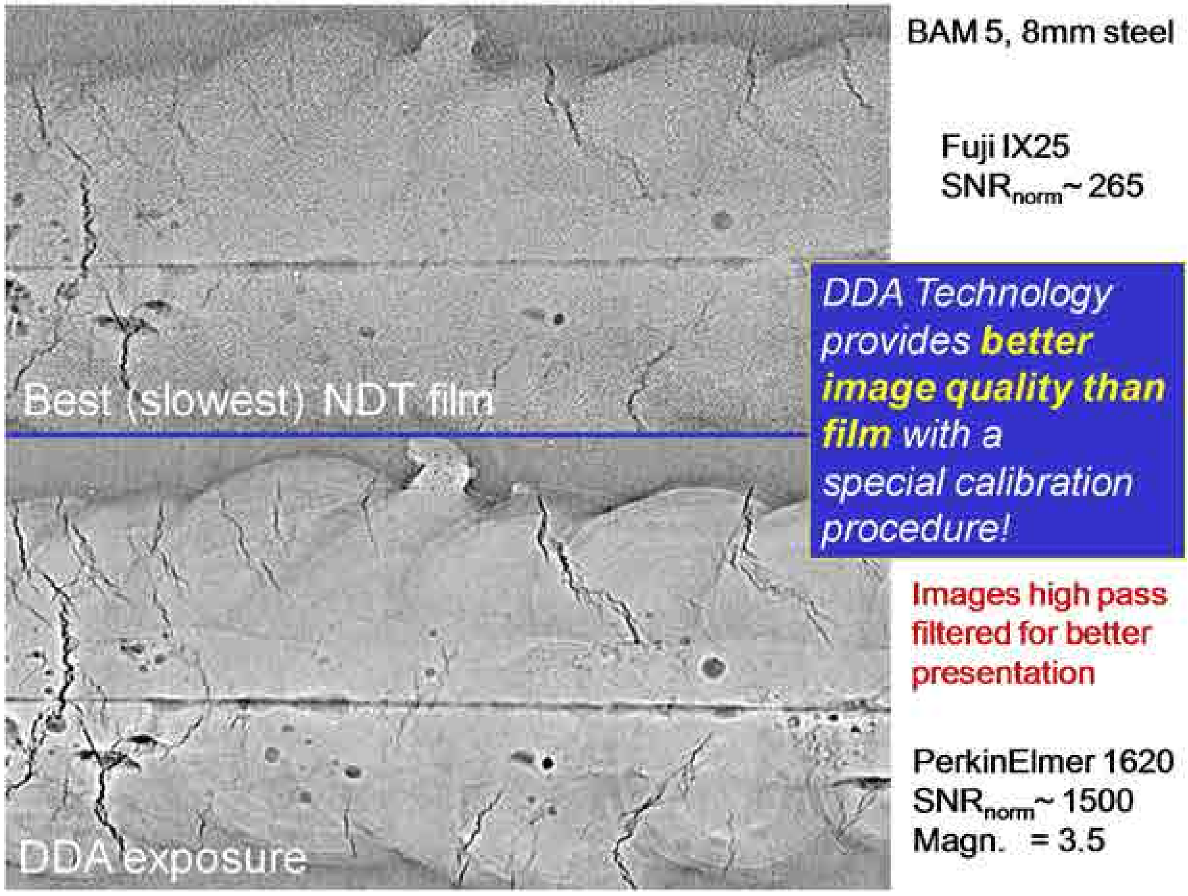

FIG. 10. Better detail visibility of flaws by increased SNR of DDA image in comparison to digitized film image of weld sample BAM 5.

Fig. 11a shows a typical example for the compensation of decreased contrast (μ_{eff}) by increased SNR. A step wedge with ASTM E 1025 IQIs (2%) was exposed at different X-ray energies and mA minutes with a constant source to detector distance. The visibility of the 2T hole (denoted with 2 in Fig. 11b) was achieved with increasing kV of the tube at shorter exposure time. This cannot be achieved with X-ray films, since they will always be exposed to an optical density between 2 and 4. In this case, the films of a given class always have the same SNR in a small range due to its specific manufacturing process. The increase of the tube voltage from 80 kV to 150 kV allows finally the reduction of exposure time down to 20% for digital radiology in the example of Fig. 11. All thickness steps of the test object can be inspected with one exposure at 150 kV. The steps with the smallest thickness are even radiographed with 2-1T quality. Here, the tube voltage increase yields a higher efficiency and an increased thickness range based on the digital “high contrast sensitivity” technique.

FIG. 11a. Step wedge of steel with ASTM E 1025 IQIs for determination of image quality.

80kV	1 mA min	2 mA min	5 mA min	10 mA min	20 mA min
0,05 in	1	2	1	1	1
0,07 in	4	2	2	2	1
0,10 in	-	2	2	2	1
0,12 in	4	4	2	2	1
0,15 in	-	-	2	2	2
0,20 in	-	-	-	2	2
0,25 in	-	-	-	-	4

100kV	1 mA min	2 mA min	5 mA min	10 mA min	20 mA min
0,05 in	2	1	1	1	1
0,07 in	2	2	1	1	1
0,10 in	2	2	1	1	1
0,12 in	2	2	1	1	1
0,15 in	4	2	2	1	1
0,20 in	-	4	2	1	1
0,25 in	-	-	1	?	1

150kV	1 mA min	2 mA min	5 mA min	10 mA min	20 mA min
0,05 in	2	1	1	?	?
0,07 in	2	1	1	?	?
0,10 in	2	2	1	?	?
0,12 in	2	2	2	1	?
0,15 in	2	2	2	1	1
0,20 in	4	2	2	1	1
0,25 in	4	2	2	1	2

FIG. 11b. Achieved IQI quality (smallest visible hole of 2% IQI. It means: 1: 1T hole, 2: 2T hole, 4: 4T hole) as function of kV, mAmin and wall thickness in inch for test object of Fig. 11 a.

As consequence the requirements for film radiography in relation to the maximum tube voltage (EN 1435, EN 444, ISO 17636:2003) are not valid anymore for digital radiography. It is proposed for CD ISO 17636-2 to modify as follows:

- To maintain good flaw sensitivity, the X-ray tube voltage should be as low as possible. The recommended maximum values of tube voltage versus thickness are given in Fig. 20 of ISO 17636-2:2013.
- These maximum values are best practice values for film radiography.
- DDAs provide sufficient image quality at significant higher voltages too.
- Highly sensitive imaging plates with high structure noise of plate crystals (coarse grained) should be applied with about 20 % less X-ray energy as indicated in Fig. 20 of ISO 17636-2:2013.
- High definition imaging plates, which are exposed similar to X-ray films and having low structure noise (fine grained) can be exposed with X-ray energies of Fig. 12 (from ISO 17636-2:2013) or significantly higher if the SNR is sufficiently increased.

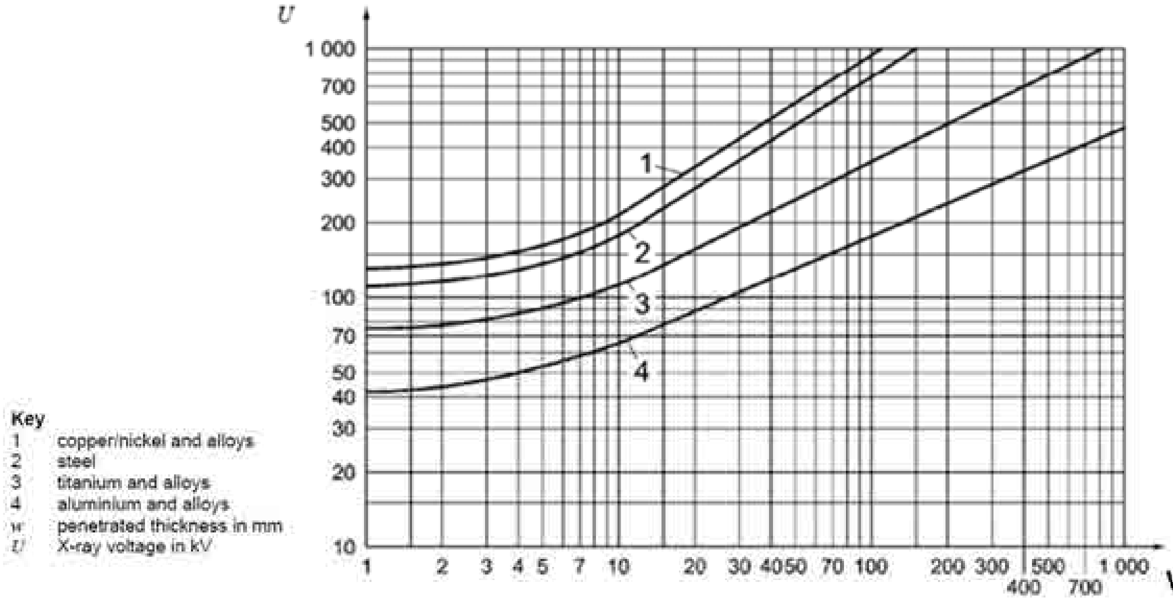

FIG. 12. Selection of Exposure Voltage of X-ray Tube becomes a Recommendation for Digital Detectors (see ISO 17636-1 and -2 for X Ray devices up to 1 000 kV as a function of penetrated thickness and material).

Compensation Principle II:

Compensation of insufficient detector sharpness (higher unsharpness) by increased SNR.

The European standard EN 14784-2 requires the application of high definition CR systems for X-ray inspection with pixel sizes of less than 50µm for class B inspection (for wall thickness <12 mm and tube voltages <150 kV). Most available systems do not allow a resolution below 50µm pixel size and are excluded for industrial X-ray applications at thin wall thicknesses in Europe. Recent trials have shown that DDAs provide a better image quality and IQI visibility than industrial X-ray films [13, 14]. In a high contrast sensitivity mode the DDAs achieve better IQI reading than film exposures. This effect is observed when subpixel contrast resolution is achieved. This is the case, if the SNR at the detector is increased considerably. If a wire or crack is smaller than a pixel, it still influences the contrast and can be seen in the image if the contrast is sufficiently higher than the noise. Therefore, systems with insufficient spatial resolution can be applied if their higher unsharpness is compensated by increased SNR.

Fig. 13 shows the copy of revised table for hardware selection of CD ISO 17636-1 (class B) which is widely conforming to the ISO 10893-7:2010. No DDA or CR system shall be used, which does not provide the required basic spatial resolution, as defined in Tables B.13, B. 14 of CD ISO 17636-2. If the available digital system has not sufficient spatial resolution, it may be used on basis of the compensation (II) principle.

Image Quality Class B: Duplex wire ISO 19232-5		
Penetrated thickness w [a] mm	Minimum IQI value and maximum unsharpness (ISO 19232-5) [b] mm	Maximum basic spatial resolution (equivalent to wire thickness and spacing) [b] mm
$w \le 1{,}5$	D 13+ 0,08	0,04
$1{,}5 < w \le 4$	D 13 0,10	0,05
$4 < w \le 8$	D 12 0,125	0,063
$8 < w \le 12$	D 11 0,16	0,08
$12 < w \le 40$	D 10 0,20	0,10
$40 < w \le 120$	D 9 0,26	0,13
$120 < w \le 200$	D 8 0,32	0,16
$w > 200$	D 7 0,40	0,20

[a] For double wall technique, single image, the nominal thickness t shall be used instead of the penetrated thickness w.

[b] The IQI reading for system selection (see Annex C) applies for contact radiography. If geometric magnification technique (see 7.7) is used, the IQI reading shall be performed in the corresponding reference radiographs.

FIG. 13. Reproduction of table B.14 of ISO 17636-2:2013: Minimum requirements of digital detection systems for class B testing as function of wall thickness.

It is proposed to permit the application of unsharp systems, if the visibility of the required wire or step hole IQI is increased by compensation of missing duplex wire resolution (caused by too high basic spatial resolution values of the detection system) through SNR enhancement (see EN 462-5, ASTM E 2002 and requirements of EN 14784-2). Several new standards define minimum duplex wire values for specific applications (e.g. ISO 10893-7 or ISO 17636-2:2013). Typically, one higher (smaller diameter, see EN 462-1) single wire (resulting in higher contrast sensitivity) shall be seen through adjustment of parameters that increase the SNR if an additional duplex wire of spatial resolution is required in the system qualification for a given material thickness and application. It was proposed in CEN TC 138 WG 1 that the compensation should allow maximum 2 wire vs. wire pair compensations. The compensation should also be applicable to plate hole IQIs too. This is still under discussion.

Example: Is a digital detection system used (DDA or SR), which achieves the duplex wire pair D11 (first unsharp wire pair) for inspection of a 5 mm thick object and class B testing as defined in ISO 17636-2:2013 (required is D12 and W16), single wire W17 shall be clearly visible in the image for acceptable quality.

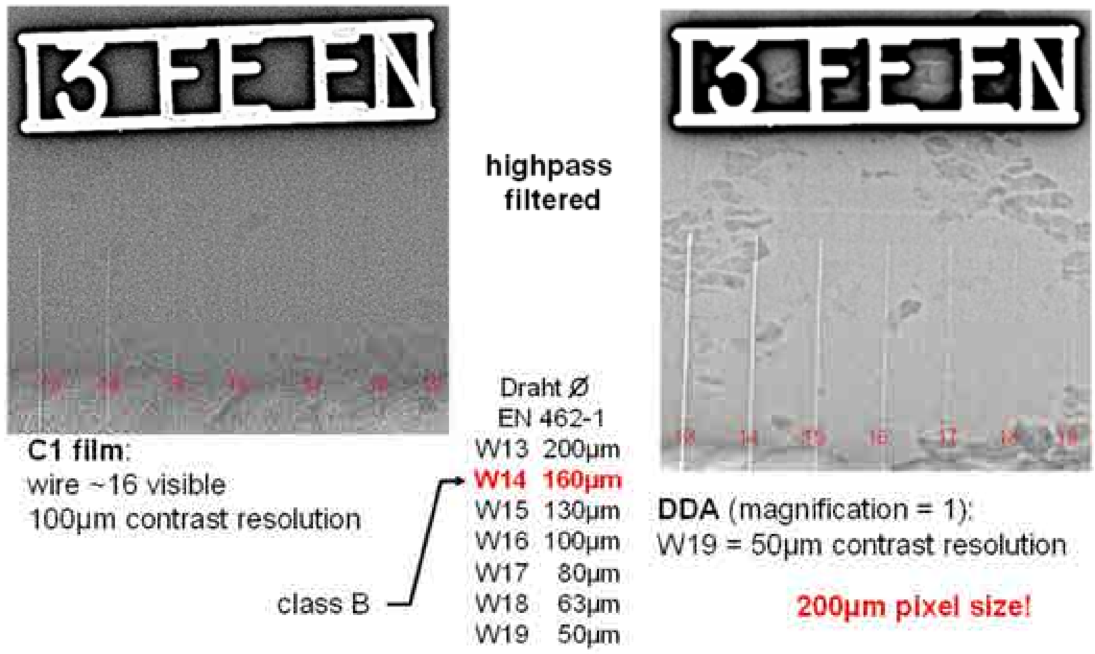

FIG. 14. Comparison of visibility of wire type IQIs according to EN 462-1 for film (left) and DDA (right) at 8mm wall thickness (images high pass filtered for better visualization). The improved SNR of the DDA allows to detect the wire W19 (50 µm diameter) at a detector pixel size of 200µm without magnification technique!

The compensation effect has been proven with a commercially available DDA (see Fig. 14). Even at a magnification of 1 and a basic spatial resolution of 200µm (pixel size), the significantly increased SNR of the DDA allows the detection of crack indications which are hidden by noise in the film image with its much better basic spatial resolution SR_b of 40µm. Fig. 14 shows the radiograph of an # 13 wire IQI on a 8 mm steel plate. The radiographs were high pass filtered for better graphical presentation. The digitized film (50 µm pixel size) shows wire number 16 (100 µm diameter) and the DDA image shows wire number 19 being visible, which has a diameter of 50 µm. Therefore, the detector shows the wire 19 indication with a subpixel resolution.

3. RT-TECHNIQUES, INDUSTRIAL SECTORS, STANDARDS AND TRAINING HOURS

3.1. RT-D TRAINING MODULES

It is proposed to subdivide the **RT** method in the following 2 techniques:

- Film Radiography (**RT-F**)
- Digital Industrial Radiology (**RT-D**)

Three training MODULEs are proposed and described in detail for the **RT-D** training in this guideline:

- **RT-D Module 1:** Training module for personnel having no RT knowledge, and entering the RT-D training course without training and certification in film radiography (**RT-F**).

  NOTE: Computed Tomography (**RT-CT**) is a very specialized technique and is considered as part of the **RT-D** training here. No special training course for **RT-CT** is proposed yet.

- **RT-D Module 2**: Training module for **RT-F** certified personnel. At minimum 50% of the **RT-D** training hours is required. This is considered as "*Film replacement course*".

  NOTE: **The RT-D Module 2**for **RT-F, level 2 (or 3),** certified personnel allows direct access to **RT-D**, level 2, without level 1 training and certification if a minimum 50% of the **RT-D**, level 1+2, training hours have been achieved. This is considered as "*Film replacement course*" for direct access to RT-D, level 2, without level 1 training and certification.

- **RT-S:** specialized training module for personnel having no knowledge on and certification in **RT-F**, but shall be trained for NDT with analogue and digital radioscopic devices for automated and semi-automated testing of castings and welds. Between 50% and 100% of the **RT-D** training hours are required. This training course is designed for personnel, which is operating **stationary RT-S** equipment for serial production of castings (e.g. car industry) and welding (e.g. pipe manufacturing industry).

3.2. DIGITAL TECHNIQUES TO CONSIDER IN RT-D

The digital industrial Radiology (**RT-D**) shall consider the following digital techniques:

- **Film Digitization**
- **Image processing**
  - Basics
  - Contrast and brightness (point operations)
  - Digital Filter
  - Measurement of dimensions
  - Semi-automated defect recognition
- **Computed Radiography**
  - Film replacement
- **Radiography with DDAs**
  - Film replacement
  - High contrast sensitivity technique

- **Radioscopy (RT-S: real time and digital)**
  - Image intensifier
  - Fluoroscopy
  - Automated and semi-automated defect recognition
- **Computed Tomography (RT-CT)**

Training and exercises have to be conducted in all RT-D techniques except that the certification is restricted to selected techniques only. The training of a restricted number of techniques can be performed in a shorter training time but the training shall be performed in at least 50% of the training hours of the RT-D training course, Module 1. The development of a written instruction/procedure has to be an essential part of training for all techniques in level 2 and 3. The training contents for the different modules are described in more detail in the syllabi in Tables 5-7, see also Annex III.

3.3. PRODUCT SECTORS AND INDUSTRIAL SECTORS

The following product sectors should be considered by the Certification Board:

- **Welded products (w)**
  - Pipes and plates
  - Boilers
  - Production and in-service testing
- **Castings (c)**
  - Castings with "radiography" like inspection (film replacement)
  - Multi angle inspection, dynamic testing
  - Serial inspection of castings without and with automated defect recognition (ADR)
- **Tubes and Pipes (t)**
  - Corrosion and erosion evaluation
  - Wall thickness measurements in tangential and double wall technique
- **Others**
  - Turbine blades, forge products, plastics, composites, ceramics, electronics, food, concrete

For radiographic testing (**RT**) the industrial sector **pre and in-service testing** combines the product sectors **w, c and t**.

All RT-D training modules should consider at least the three product sectors: Welded products (w), castings (c) and tubes and pipes (t). This should be certified under product sectors "Welds, Castings and tubes and pipes" in reference to ISO 9712:2005 or under industrial sector "Pre and in-service testing" in reference to ISO 9712:2012.

The training of a reduced number of product sectors may be performed in a shorter training time, but the training shall be performed in at least 50% of the training hours of the complete RT-D training course, Module 1 (follow specific requirements in ISO 9712:2012).

The development of a written instruction (level 2) or a written procedure (level 3) has to be trained for all techniques. The training contents for the different modules and sectors are described in more detail in the syllabi in Tables 5-7.

3.4. STANDARDS TO CONSIDER

Table 1 show the latest developments in standardization, which have to be included in the RT-D training. Table 2 shows all relevant standards (as available until 2011) which should be considered in RT-F and RT-D training of level 2 and 3.

TABLE 1. OVERVIEW OF STANDARDS ON DIGITAL INDUSTRIAL RADIOLOGY (09/2013)

Standard	Topic
EN 13068	Radioscopy
EN 14096, ISO 14096	Film Digitisation
EN 14784 CR (2005) becomes ISO 16371	Part 1: Classification of Systems, Part 2: General principles
ISO 10893-7 (2010)	Steel tubes – NDT of welds with DDA and (CR)
ISO 17636-2 (2013)	NDT of welds: CR and DDA, to substitute EN 1435
EN 16407: corrosion and wall thickness measurement	Practice with film, CR and DDA for double wall RT and tangential RT
ASME (BPVC, S.V)	Radiography with film, CR, DDA and more
ASTM CR (2005) *Under revision*	Classification (E 2446-05), Long term stability (E2445-05), Guide (E 2007-10), Practice (E 2033-06)
ASTM DDA (2010)	Characterisation (E 2597-07), Long Term Stability (E 2737-10), Guide (E 2736-10), Practice (E 2698-10)
ASTM DICONDE (2010) (data format)	Standard Practice for Digital Imaging and Communication Non destructive Evaluation (DICONDE) (E 2663-08, E 2699-10, E 2669-10, E 2738-10, E 2767-10)
ASTM Digital reference image catalogues	Light alloy, titanium and steel castings, E 2422-05, E 2660-10, E 2669-10

TABLE 2. RELEVANT STANDARDS OF ISO, CEN, ASTM AND ASME BPVC SECTION V, FOR RT-F AND RT-D TRAINING (2013)

Method	Standard Organization	Qualification	Stability tests	Guide	General practice	Welding General	Welding Practice	Welding evaluation	Casting Practice	Casting Catalogue	IQI Contrast	IQI Spatial resolution
RT-Film	ISO	11699-1	11699-2		5579	17635	17636-1	10675			19232-1 19232-2	19232-5
	CEN EN	584-1	584-2		444	17635	17636-1	10675	12681		462-1, 462-2	462-5
	ASTM E	1815		94	1742		1032		1030	155, 186, 192 242, 272, 280 310, 390, 446 505, 689, 802 1320, 1648	747, 1025	2002
	ASME BPVC				Section V Article 2		Section V Article 2 Appendix A	Section V Article 1	Section V Article 2 Appendix 7		Section V Article 2 Appendix C, D	
RT-S: Radioscopy Fluoroscope Intensifier DDA- real time	ISO					17635		10675			19232-1 19232-2	19232-5
											462-1, 462-2	462-5
	CEN EN	13068-1	13068-2	13068-1	13068-3	17635		10675				2002
	ASTM E	1411		1000	1255		1416		1734	2422 2660, 2669	747, 1025, 1647	
	ASME BPVC				Section V Article 2 Appendix 1,2,3				Section V Article 2 Appendix 7		Section V Article 2 Appendix C, D	
Film Digitisation	ISO	14096-1	14096-1		14096-2							
	CEN EN	14096-1	14096-1		14096-2							
	ASTM E	1936								2422, 2660, 2669		

TABLE 2. RELEVANT STANDARDS OF ISO, CEN, ASTM AND ASME BPVC SECTION V, FOR RT-F AND RT-D TRAINING (2013) (cont.)

Method	Standard Organization	Qualification	Stability tests	Guide	General practice	Welding General	Welding Practice	Welding evaluation	Casting Practice	Casting Catalogue	IQI Contrast	IQI Spatial resolution
RT-D: CR	ISO	16371-1	16371-1			17635	17636-2 10893-7	10675			19232-1,2	19232-5
	CEN EN	14784-1	14784-1		14784-2	17635	17636-2	10675			462-1, 462-2	462-5
	ASTM E	2446	2445	2007	2033					2422 2660, 2669	747 1025	2002
	ASME BPVC				Section V Article 2 Appendix 8		Section V Article 2 Appendix A	Section V Article 1	Section V Article 2 Appendix 7		Section V Article 2 Appendix C, D	
RT-D: DDA	ISO					17635	17636-2	10675			19232-1 19232-2	19232-5
	CEN EN					17635	17636-2	10675			462-1, 462-2	462-5
	ASTM E	2597	2737	2736	2698					2422, 2660, 2669	747 1025	2002
	ASME BPVC				Section V Article 2 Appendix 9		Section V Article 2 Appendix A	Section V Article 1			Section V Article 2 Appendix C, D	
Radiation Source size	ISO				3999-1							
	CEN EN				12679							
	ASTM E				1114							
Focal spot Size	ISO											
	CEN EN				12543-1/5							
	ASTM E				1165, 2903							
Computed tomography	ISO			15708-1	15708-2							
	CEN EN	16016-4		16016-2/1	16016-3							
	ASTM E	1695		1441, 1672	1570, 1935				1814			
DICONDE Data format	CEN EN				CR 13935							
	ASTM E				2663, 2699,2669, 2738, 2767							

3.5. REQUIRED TRAINING HOURS

The required training hours are derived from ISO 9712:2012. Furthermore, TECDOC-628/Rev.2 is considered as a secondary reference document. No significant discrepancy is observed for RT-F training between ISO 9712:2012 and TECDOC-628/Rev.2. The requirements for other NDT methods differ, but this is irrelevant for this guideline.

The US MAI (Metals Affordability Initiative) document recommends in Appendix C for the RT-D training (training of certified film radiographers) in level 1:

- 8 hours formal training, 20 hours on the job experience and a specific and practical Examination.
- 40 hours formal training, 120 hours on the job experience and a specific and practical Examination.
- The training hours are recommended for training in CR or DDA application. For training in both techniques the hours may be combined in agreement with the employer's written practice.
- No recommendation is given for level 3 training.

For level 2 this corresponds to 50% of the training hours which are required by ISO 9712:2012 and TECDOC-628/Rev.2 for the RT-F technique in conformance to the proposals in this guideline.

Table 3 contains the proposed numbers of hours for the RT-D training, which are equivalent to the RT-F training hours. The footnotes describe conditions for reduction of training hours.

TABLE 3. MINIMUM TRAINING HOURS AS REQUIRED BY ISO 9712:2012 (EQUIVALENT TO TECDOC-628/REV.2 FOR RT-F), WITH EXTENSIONS BY DIFFERENT RT TECHNIQUES

NDT Method	**Level 1** in hours	**Level 2** in hours	**Level 3** in hours
RT-F	40	80	40
[a,b] ***RT-D***	40	80	40

a) Training duration may be reduced by up to 50 %:
- for RT-D training of personnel, certified in the same or higher RT-F level
- in only one technique, as training using only Radioscopy (RT-S) is sought

b) **60** hours are required for direct access to level 2 without RT-D, level 1, training and RT-D, level 1, examination of personnel being certified in the same or higher RT-F level.

The ISO 9712:2012 requires:

"7.2.3 The minimum duration of training undertaken by the candidate for certification shall be as defined in 7.2.4 and Table 3 (corresponds to Table 2 in ISO 9712:2012) for the applicable NDT method, with the possible reductions defined in 7.2.5. or Table 3[a)] (corresponds to Table 2 in ISO 9712:2012). This duration is based upon candidates possessing adequate mathematical skills and prior knowledge of materials and processes. If it is not the case,

additional training may be required by the certification body. Training hours include both practical and theoretical courses.

7.2.4 *Direct access to level 2 requires the total hours shown in Table 3 (corresponds to Table 2 in ISO 9712:2012) for levels 1 and 2. Direct access to level 3 requires the total hours shown in Table 3 (corresponds to Table 2 in ISO 9712:2012) for levels 1, 2 and 3. When considering the responsibilities of a certified level 3 (see 6.3 of ISO 9712:2012) and the content of the Part C of the basic examination for level 3 (see Table 6 of ISO 9712:2012), additional training about the other NDT methods may be necessary.*

7.2.5 *The possible reductions in training duration are as described hereafter, provided that, when several reductions are applicable, the total reduction does not exceed 50 % of the training duration. Any reduction does require acceptance by the certification body.*

- *For all levels:*

- *For candidates seeking certification in more than one method (e.g. VT, MT, PT) or already certificated and seeking certification in another method, when the used training syllabus duplicates certain aspects (e.g. product technology), the total number of training hours for these methods (e.g. VT, PT, MT) may be reduced in line with the training syllabus.*
- *For candidates who have graduated from technical college or university, or have completed at least two years of engineering or science study at college or university, the total required number of training hours may be reduced by up to 50 %.*
- *For levels 1 and 2: When the certification sought is limited:*
- *in application (e.g., automated ET, FLT, UT of bar, tube and rod, or normal beam ultrasonic thickness and lamination testing of rolled steel plate), or*
- *in technique (e.g. RT using only* ***Radioscopy****), the training duration may be reduced by up to 50%.*

  - *For direct access to level 2 RT when certification is restricted to the interpretation of film* ***or digital images***[a] *and to only one product sector, a minimum training requirement of 56 h applies."*

Designation of training hours for different training contents can be found in the following Tables (see syllabi). No special reduction of training hours is proposed for candidates who have graduated from technical college or university, or have completed at least two years of engineering or science study at college or university in this guideline. These personnel may be certified with reduced experience times, if agreed by the certifying body.

ISO 9712:2012 and TECDOC-628/Rev.2 require for RT level 1 training 40 hours.

[a] ***modified in addition to ISO 9712:2012.***

4. TRAINING SYLLABI

The training syllabi are derived from the Guideline TECDOC-628/Rev.2, ISO 9712:2012, the German documents of the German Society for NDT, the MAI document and the current training booklet for level 2 training of IAEA. Also some information was taken from the results of the European Leonardo project [7].

The minimum duration of training undertaken by the candidate for certification in RT-D module 1 is defined in Table 5. The duration is based upon candidates possessing adequate mathematical skills and prior knowledge of materials and processes. If it is not the case, additional training may be required by the certification body. Training hours include both practical and theoretical courses.

Direct access to level 2 requires the total hours shown in Table 3 and 5 for levels 1 and 2. Direct access to level 3 requires the total hours shown in Table 3 and 5 for levels 1, 2 and 3.

Since regulations may exist for the radiation safety of personnel and handling of isotopic sources with separate training requirements in the different countries, the training hours are reduced in RT-D and RT-S (see Tables 5-7) down to two hours in the syllabi. Personnel has to prove the extra training and if required certification on basis on the national regulations and laws on radiation safety. Otherwise the training hours for radiation safety shall be extended in the RT-D and RT-S training course in agreement with TECDOC-628.

Furthermore, the training subject "general knowledge", which is recommended in TECDOC-628 was shortened due to the enormous amount of other training subjects in digital radiology. The reference to other NDT methods and material defectology is partly integrated in the subject "Application and Standards".

Different Syllabi are recommended for the training courses RT-D module 1 and 2 and RT-S (see Tables 5-7).

Since Computed Tomography is not yet a common technique in the IAEA member states and the major industries, a separated training syllabus for CT is not recommended yet. CT will be introduced by a lecture and a numeric modeling based exercise. If specialized training of CT is required, the training hours may be increased or a separated training course may be conducted.

Table 6 and Table 7 show the breakdown of training hours for RT-D module 2 for RT-F certified personal (film replacement), and for radioscopy operators (RT-S) in serial production, without required certification. Due to the serious differences in the training contents between RT-F, RT-S and RT-D, it is recommended in this guideline to increase the training hours for RT-D module 2 and RT-S to more hours than required by the 50% rule of Table 3. The required hours for training in RT-D and RT-S, Module 2, are listed in Table 9.

4.1. TRAINING CONTENTS FOR DIFFERENT SUBJECTS

Tables 5-7 describe the coarse syllabi for the three training modules RT-D, Module 1 and 2 and RT-S. Training organizations may modify the proposed number of hours depending on the national needs.

The MAI document [6] describes also a syllabus for RT-D training in level 1-3, which is similar to Table 4 and Tables 5-7, but shows also some differences. In the Leonardo [7] project complete training handbooks were published for RT-F, considering some digital and tomographic aspects. Relevant training contents as required for RT-F in ISO TR 25107 [8] should be considered for RT-D and RT-S as well.

The following contents (Table 4) shall be considered in this guideline with different weighting for level 1-3 in the RT-D and RT-S training. Training organizations may modify the proposed contents of Table 4 depending on the national needs:

TABLE 4. SYLLABUS WITH BREAKDOWN OF TRAINING CONTENTS

		Level 1	Level 2	Level 3
General principles of NDT				
	Origin of discontinuities	X	X	a)
	Need for NDT			
	NDT methods – Principles, advantages, applications and limitations		X	a)
	Material and processes		X	a)
Physical principles				
General	Structure of the atom	X	X	X
	Atomic model		X	X
	Electromagnetic spectrum	X	X	X
	Sources of radiation, their properties, X-rays, Gamma rays	X	X	X
	Neutrons			X
	X-ray and Gamma ray spectrum		X	X
	Essential radiographic parameters (voltage, current, activity)	X	X	X
	Filters		X	X
	Focal sport		X	X
Attenuation of radiation	General mechanism of interaction	X	X	X
	- Photoelectric effect		X	X
	- Compton effect		X	X
	- Pair production		X	X
	HVL, TVL and attenuation law	X	X	X
	Hardening of radiation, filtering, collimation		X	X
	Scattered radiation and build-up factor		X	X
	Fluorescence			X
	Attenuation of neutrons and electrons			X
Radiation contrast, noise	Contrast and noise	X	X	X
	Specific contrast		X	X
	Scatter influence	X	X	X
	Signal –to-noise ratio	X	X	X
	Contrast-to-noise ratio		X	X
	Basic spatial resolution		X	X
	Pixel size	X	X	X
	Normalised SNR_N		X	X

TABLE 4. SYLLABUS WITH BREAKDOWN OF TRAINING CONTENTS (cont.)

		Level 1	Level 2	Level 3
Optimisation of image quality	Compensation principles	X	X	X
	- Contrast vs. SNR		X	X
	- Basic spatial resolution vs. SNR		X	X
	- Local unsharpness vs. SNR			X
	Scatter protection	X	X	X
	Maximum/optimum X-ray voltage		X	X
Geometric projection conditions	Geometric and inherent unsharpness	X	X	X
	Geometric magnification		X	X
	Effect of magnification	X	X	X
	- Optimum magnification		b)	X
	- Difference between Radiography and Radioscopy		X	X
	Law of the squared distances	X	X	X
Image quality indicators, standards	Wire type	X	X	X
	Step hole type	X	X	X
	Plate hole type	X	X	X
	Duplex wire type	X	X	X
	Measurement of basic spatial resolution		X	X
	Converging line pairs		X	X
	Line pair gauges (MTF)			X
	Standards (see clause Table 2)		X	X
Equipment and work parameters				
Radiation sources	X-ray sources			
	- Standard sources	X	X	X
	- Special sources		X	X
	- Generation of high voltage		X	X
	- Cooling	X	X	X
	- Handling	X	X	X
	- Parameters: kV, mA, spot size			X
	- Measurement of parameters			
	Gamma sources and containers			
	- Handling and projector	X	X	X
	- Special design			X
	- Parameters: isotope, activity, source size	X	X	X

TABLE 4. SYLLABUS WITH BREAKDOWN OF TRAINING CONTENTS (cont.)

Detectors		**Level 1**	**Level 2**	**Level 3**
CR, imaging plates	Phosphor imaging plates Introduction and design	X	X	X
	Imaging plate and CR scanner	X	X	X
	CR system and classification		X	X
	Quality insurance (phantom)		X	X
	Exposure conditions and diagrams		X	X
	Handling	X	X	X
	System detection			X
DDAs	Digital Detector Array (DDA) introduction and design	X	X	X
	- Indirect converting		X	X
	- Direct converting		X	X
	- CCD, amorph Si, CMOS		X	X
	Detector calibration		X	X
	Quality assurance (phantom)		X	X
	Exposure conditions and diagrams		X	X
	Handling	X	X	X
	System selection			X
LDAs	Line Detector Array (LDA) Introduction and design		b)	X
	Application areas		b)	X
	Comparison to DDAs		b)	X
	Quality assurance (phantom)		b)	X
	Exposure conditions and diagrams		b)	X
	Handling		b)	X
	System selection			X
Intensifiers, Fluoroscopes	Introduction and design	X	X	X
	Application areas	X	X	X
	Quality assurance (phantom)		X	X
	Exposure conditions and diagrams		X	X
	Handling	X	X	X
	System selection			X
	Comparison to DDAs			X
Film digitization	Scanner design (camera based, line scanners, laser scanners)		X	X
	Quality assurance (phantom)		X	X
	Handling, archiving	X	X	X
	System selection			X
	Classification		X	X
Data acquisition, detector calibration	A/D interface	X	X	X
	Computer structure (processor, memory, bus, disk, load and save digital images, image formats)	X	X	X

TABLE 4. SYLLABUS WITH BREAKDOWN OF TRAINING CONTENTS (cont.)

		Level 1	Level 2	Level 3
	Image integration (on chip, in memory, optimum gain and latitude settings, accumulation vs. integration)		X	X
Digital image processing	Image structure, quantisation (bits and Bytes)	X	X	X
	Basic operation - Picture element (pixel) - Grey value	X	X	X
	Point operations - Contrast, brightness, gamma correction - Histogram - Look up Table (LUT)	X	X X X	X X X
	Matrix operations , filters - Smoothing, improvement of SNR - High pass, gradient - Edge enhancement, line extraction - median		X	X
	Measurement tools - Calibration - Line profile - Measurement of flaw length - Measurement of areas - Measurement of depth		X	X
	Correction of raw data - Linearization, Look up Table (LUT) correction - Bad pixel interpolation		X	X
Standards	Guides		X	X
	Qualification of sources			X
	General qualification of detectors			X
	User qualification of detectors		X	X
	See Table 2			X
Defectology, digital catalogues	General Welding (ISO 6520) and Casting Defects (ASTM casting catalogues)	X	X	X
	Evaluation of welding : IIW catalogue ISO 5817		X	X
	Evaluation of Casting: ASTM catalogues		X	X
	Corrosion	X	X	X
Automated image interpretation	Principles		X	X
	Binarisation		X	X
	Measurement of dimensions		X	X

TABLE 4. SYLLABUS WITH BREAKDOWN OF TRAINING CONTENTS (cont.)

		Level 1	Level 2	Level 3
[b] **Special techniques, computed tomography**	Stereo radiography		X	X
	Laminography			X
	Computed Tomography - Inspection geometry - 2D vs. 3D - Reconstruction principles - Filtered back projection - Applications - Requirements and limit of method		X	X
	See also clause 4.4			X extra
Applications Standard practice and evaluation Selection of technique	Welds - Standard practice with different exposure geometries - Interpretation of digital images - Digital processing of images - Evaluation of flaws - Measurement of flaw dimensions - Written instruction/procedure	X	X	X
	Castings - Standard practice with different exposure geometries - Interpretation of digital images - Digital processing of images - Evaluation of flaws - Use of catalogues (see above) - Measurement of flaw dimensions - Written instruction/procedure	X	X	X
	Corrosion wall thickness measurement - Tangential RT - Double wall RT - Calibration of digital images - Measurement of thickness - Written instruction/procedure	X	X	X
	Others…		X	X
Written procedure/ instructions	Welds		X	X
	Castings		X	X
	Corrosion with thickness measurement		X	X
Radiation protection	Training courses depending on national regulations	c)	c)	c)

Notes:

a) In addition to the above 40 hours a general knowledge common core course for level 3 (applicable to all NDT methods) is recommended, which shall be successfully completed only once.
b) Especially for RT-CT/RT-S related training.
c) National laws and regulations are to be considered for training on radiation safety and handling of radiation sources. Radiation safety may be trained in separated courses, or training hours should be considered to be additional to those of the syllabus requirements (see TECDOC-628/Rev.2).

4.2. EXAMPLE OF RECOMMENDED PRACTICAL EXERCISES FOR PRACTICAL TRAINING IN RT-D MODULE 2, LEVEL 2

The practical training should be organized by written exercises with description of training tasks and forms for analysis of the performed experiments. The exercises (about 4 hours per day) should be carried out at all seven days of training for RT-D module 2 as follows:

- 1st day setup of computers, monitor test, installation of training software
    - Training in handling of viewer software, brightness, contrast control
    - Measuring of image quality (Wires, duplex wire, plate holes, step holes)
        - Determination of basic spatial resolution, SNR, CNR and μ_{eff}
    - Viewing of test images
- 2nd day film digitization with reference films or CR of quality assurance phantom or radioscopy
    - Digitization of reference film or exposure of CR phantom (Film: ASTM E 1936, CR: ASTM E 2445)
    - Analysis of image quality
    - Documentation
- 3rd day test measurements with digital detector arrays of castings by standard practice ASTM E 2698 and application of ASTM digital reference catalogues
    - Selection of exposure conditions
    - Exposure of test objects (casting)
    - Analysis of image quality, evaluation of detected flaws with digital catalogues
    - Written procedure and documentation
- 4th day measurement of exposure diagram for CR by draft ASTM 2033 or ISO 17636-2
- 5th day test measurements with computed radiography of welds by standard practice ISO 17636-2 and ASME BPVC S. V and TRT for pipe walls.
    - Exposure of test objects (welds, pipes)
    - Analysis of image quality, evaluation of detected flaws by ISO 5817 and
    - Wall thickness measurement
    - Documentation
- 6th day Virtual training
    - CT,
    - Flaw segmentation
    - Defect measurement
    - Virtual optimization of exposure conditions
- 7th day optimization of image processing and training of written procedure for image processing.

TABLE 5. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 1

Syllabus for Digital Industrial Radiology RT-D - Module 1

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
General knowledge NDT	1	0	2.5	0	a)	0
Physical principles of X-ray technique	2	0.25	4.75	0	2.45	0
Radiation contrast, noise	1.5	1	3	3.5	1.2	0
[b)] **Geometrical projection conditions**	1.5	2	1	1.5	1	0.5
Optimisation of image quality	1	1	1.75	1.5	1.5	0
Image quality indicators, standards	1	2	1	0	0.5	0.5
Equipment and work – Radiation sources - X-Ray sources - Gamma sources	2	2	3.5	2	2.5	0.5
Equipment and work – detectors : CR, imaging plates	2	2	1.75	2.25	1.5	0.5
Equipment and work – detectors : DDAs	2	2	2	2	2	0
Equipment and work – detectors : LDAs	0	0	0.5	0	1	0
Equipment and work – detectors : intensifiers, fluoroscope	0	0	1.25	0.25	1	0
Equipment and work – detectors : film digitization	0	0	0.5	0	0.5	0
Data acquisition, detector calibration	0	0	2	2	1	1
Digital image processing (total)	2	2.75	7	7	3.1	2.5
Image structure, quantisation (bits and bytes)	0.25		0.5		0.25	
Basic operation	0.75	1	0.5		0.25	
Point operations	1	1	1	1	0.25	0.5
Matrix operations, filter			3	3	1.5	1
Measurement tools		0.75	1	2	0.35	1
Correction of raw data			1	1	0.5	

Syllabus for Digital Industrial Radiology RT-D - Module 1 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Standards	1	0	3	1.5	3	0
Defectology, digital catalogues	0.5	0.5	1	2.5	0.75	1
Automated image interpretation	0	0	1	1	1	0
[b] **Special techniques, computed tomography**	0	0	1	1	1.5	0.5
Applications, standard practices and evaluation (total)	2	3	2.5	6	2	2.5
Welds	1	1	1	3	1	1
Castings	1	1	1	2	0.5	1
Corrosion wall thickness measurement		1		1		0.5
Others…			0.5		0.5	
Written procedure/ instructions (total)	0	0	1	2	0	2
Welds			0.5	0.75		0.75
Castings			0.5	0.75		0.75
Corrosion wall thickness measurement				0.5		0.5
[c] **Radiation protection**	1	1	1	1	1	0
Total	**20.5**	**20**	**43**	**37**	**28.5**	**11.5**
	40		**80**		**40**	

Notes:

a) in addition to the above 40 hours a general knowledge common core course for level 3 (applicable to all NDT methods) is recommended, which shall be successfully completed only once

b) More hours are recommended for RT-CT related training

c) National laws and regulations are to be considered for training on radiation safety and handling of radiation sources. Radiation safety may be trained in separated courses, or training hours should be considered to be additional to those of the syllabus requirements (see TEC-DOC-628/Rev.2).

TABLE 6. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 2

Syllabus for Digital Industrial Radiology RT-D - Module 2

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
General knowledge NDT	0	0	0	0	a)	0
Physical principles of X-ray technique	0.9	0.2	1	0	1.4	0
Radiation contrast, noise	0.9	0	1.5	1.5	1.2	0
b) **Geometrical projection conditions**	1	1	0.5	b)	1	b)
Optimisation of image quality	1	0	1	1	1	0
Image quality indicators, standards	1	1	0	0	0	0
Equipment and work – Radiation sources - X-Ray sources - Gamma sources	1	2	4	1	2	0
Equipment and work – detectors : CR, imaging plates	1.5	2	2	2	1	1
Equipment and work – detectors : DDAs	1.5	2	2	2	1.5	0.5
Equipment and work – detectors : LDAs	0	0	0.5	0	0.5	0
Equipment and work – detectors : intensifiers, fluoroscope	0.5	0	0.5	1	0.5	0
Equipment and work – detectors : film digitization	0	0	0.5	0	0	0
Data acquisition, detector calibration	0	0	1	1	1	0
Digital image processing (total)	2.5	2	6	4	3	3
Image structure, quantisation (bits and bytes)	0.5		0.5		0.25	
Basic operation	1	1	0.5		0.25	
Point operations	1	1	0.5	0.5	0.5	0.5
Matrix operations, filter			2.5	1	1.5	1.5
Measurement tools			1	1.5		1
Correction of raw data			1	1	0.5	

Syllabus for Digital Industrial Radiology RT-D - Module 2 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Standards	0.5	0.5	3	3	2	0
Defectology, digital catalogues	0.25	0.75	1	1	0.5	0.5
Automated image interpretation	0	0	1	1	0.5	0.5
[b] **Special techniques, computed tomography**	0	0	1	1	1	0
Applications, standard practices and evaluation (total)	3	3	3.5	5.5	2.5	3
Welds	1	1	1	1.5	1	1
Castings	1	1	1	1.5	0.5	1
Corrosion wall thickness measurement	1	1	0.5	1.5	0.5	1
Others…			1	1	0.5	
Written procedure/ instructions (total)	0	0	1.5	1.5	1	0.5
Welds			0.5	0.5	0.5	
Castings			0.5	0.5	0.5	
Corrosion wall thickness measurement			0.5	0.5		0.5
[c]**Radiation protection**	1	1	1	1	1	0.4
Total	**16.55**	**15.5**	**32.5**	**27.5**	**22.6**	**9.4**
	32		**60**		**32**	

Notes:

a) in addition to the above 40 hours a general knowledge common core course for level 3 (applicable to all NDT methods) is recommended, which shall be successfully completed only once

b) More hours are recommended for RT-CT related training

c) National laws and regulations are to be considered for training on radiation safety and handling of radiation sources. Radiation safety may be trained in separated courses, or training hours should be considered to be additional to those of the syllabus requirements (see TECDOC-628/Rev.2).

TABLE 7. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-S

Syllabus for Digital Industrial Radiology RT-S

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
General knowledge NDT	0	0	0	0	a)	0
Physical principles of X-ray technique	1	0.5	1	0	1	0
Radiation contrast, noise	1	0	1	1	1	0
[b] **Geometrical projection conditions**	1.5	2	2	2	2	1
Optimisation of image quality	1	0	1	1	1	0
Image quality indicators, standards	1	1	0	0	0	0
Equipment and work – Radiation sources - X-Ray sources - Gamma sources	1	2	1	1	1.5	0
Equipment and work – detectors : CR, imaging plates	1	0	1	0	1	0
Equipment and work – detectors : DDAs	1.5	1	1	1	1	1
Equipment and work – detectors : LDAs	0.5	0	0.5	0	0.5	0
Equipment and work – detectors : intensifiers, fluoroscope	1	1	1	1	0.5	0.5
Equipment and work – detectors : film digitization	0	0	0	0	0	0
Data acquisition, detector calibration	0	0	1	1	1	0
Digital image processing (total)	2	2	5	4	3	3
Image structure, quantisation (bits and bytes)	0.5		0.5		0.25	
Basic operation	0.75	1	0.5		0.25	
Point operations	0.75	1	0.5	0.5	0.5	0.5
Matrix operations, filter			2	1	1.5	1.5
Measurement tools			0.5	1.5		1
Correction of raw data			1	1	0.5	

Syllabus for Digital Industrial Radiology RT-S (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Standards	1	1	3	3	2	0
Defectology, digital catalogues	0.5	0.5	1	1	0.5	0
Automated image interpretation	0	0	1	1	0.5	0.5
[b] **Special techniques, computed tomography**	0	0	1	1	0.5	0.5
Applications, standard practices and evaluation (total)	2	3	2.5	2	1.5	2
Welds	1	1.5	1	1	0.5	1
Castings	1	1.5	1	1	0.5	1
Corrosion wall thickness measurement						
Others…			0.5		0.5	
Written procedure/ instructions (total)	0	0	1	1	1	1
Welds			0.5	0.5	0.5	0.5
Castings			0.5	0.5	0.5	0.5
Corrosion wall thickness measurement						
[c] **Radiation protection**	1	1	1	1	1	1
Total	**17**	**15**	**26**	**22**	**21.5**	**10.5**
	32		**48**		**32**	

Notes:

a) in addition to the above 40 hours a general knowledge common core course for level 3 (applicable to all NDT methods) is recommended, which shall be successfully completed only once

b) More hours are recommended for RT-CT related training

c) National laws and regulations are to be considered for training on radiation safety and handling of radiation sources. Radiation safety may be trained in separated courses, or training hours should be considered to be additional to those of the syllabus requirements (see TECDOC-628/Rev.2).

4.3. TRAINING COMPUTED TOMOGRAPHY

It is recommended to develop a separated training course for computed tomography (RT-CT) if required. Computed tomography is a very specialized technology and should be combined with instructions on handling of the CT device and CT software, depending on the manufacturer's manual. Nevertheless, CT was included as informative training in level 2 and 3 since it is essential that RT-DR personnel have knowledge and an understanding of the basics and potential of this technology.

The MAI document [6] proposes to include CT in the level 3 training, extensively. The following syllabus is recommended in this document for CT as part of level 3 training:

Computed tomography testing:

- Difference between CT and conventional radiography;
- Benefits and Advantages;
- Limitations;
- Industrial imaging examples;
- Basic Hardware Configuration;
- Scan geometries – general configurations by generation;
- Radiation sources;
- Detection systems;
- Convolution/Back projections;
- Fourier Reconstructions;
- Fan / Cone Beam;
- Advanced Image Processing and Algorithm Analysis;
- Fundamental CT Performance Parameters;
- System performance analysis;
- Fundamental scan plan parameters;
- Basic system tradeoffs for spatial resolution/noise/slice thickness;
- Basic Image Interpretation;
- Artifacts – definitions, detection and basic causes.

A part of these requirements is covered in lecture L16 as described in Annex I for level 2 training. Practical training is not included in the current training program. Since most NDT training organisations do not have CT equipment, virtual training is proposed, e.g. with the aRTist training software (see clause 5 and [12]), which would require an extension of the training hours.

5. VIRTUAL TRAINING FOR RT-D AND CT

The practical training with computed radiography devices, X-ray intensifiers or digital detector arrays, requires expensive hardware with costs of up to US$150,000 per system and the training is very time consuming because the personnel cannot train in the same room due to radiation protection concerns. Practical training, therefore, has to be organized in groups and each group has to wait until the previous group has finalized their training.

Virtual training tools for training of digital radiography are available for computer based application [12]. The advantages are:

- All trainees can work in parallel with different exposure techniques.
- No radiation protection has to be considered.
- No waiting times are required except handling at the computer and documentation of results.

Disadvantages are:

- Trainees do not train RT-D under practical conditions with real hardware
- No training of hardware specific handling is performed
- No practical radiation protection measures are trained

In conclusion the practical training in one or two techniques may be substituted by virtual training, but at least one technique (CR, DDA or Radioscopy with intensifier or fluoroscope) shall be trained under real radiation conditions.

The virtual training with the software package aRTist [12] was successfully used for training of virtual inspection of welds, castings, pipes and for Computed Tomography. Training was performed in 2009 in India and Malaysia and 2010 in Republic of Korea. It is also used for level 3 RT training by the DGZfP.

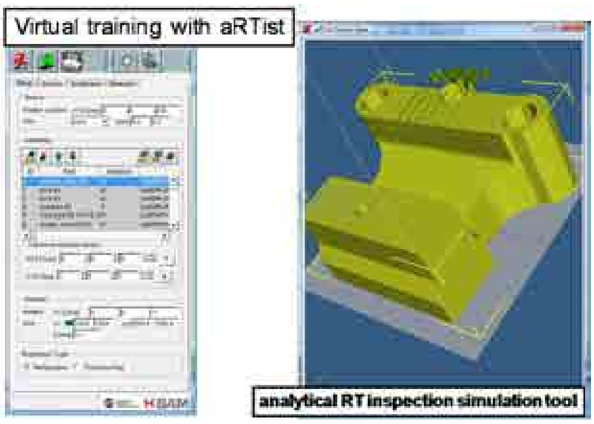

FIG. 15a.

Virtual inspection of an aluminum casting with flaws and IQIs [12].
Left: Opening window of aRTist software package, controlling the inspection parameters.
Right: CAD of the test piece for virtual inspection.

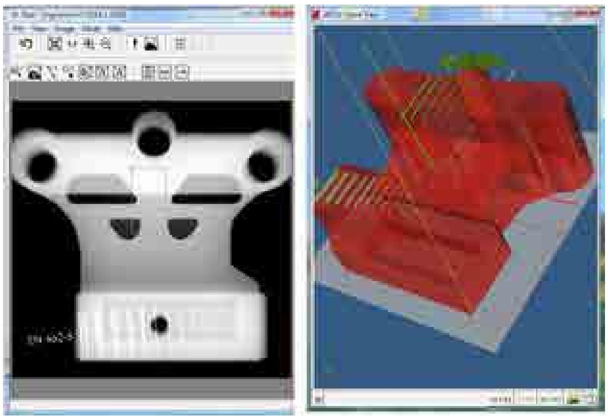

FIG. 15b.

Left: Result of virtual X-ray inspection.
Right: Presentation of the test piece in transparent mode for visualization of the flaws.

FIG.15. Typical image of a RT-D inspection of a light alloy castings.

Fig. 15 shows a typical image of a RT-D inspection of a light alloy casting. The surface data of the casting, the IQIs and the flaws, are provided as CAD file in .stl format. A combined material specific data set is provided for different test objects with flaws and IQIs. The students select the correct exposure conditions as e.g. X-ray voltage, source detector distance, focal spot size, detector type and detector parameters. Then, they calculate the corresponding digital radiograph with the modeling software. The IQI values, SNR, basic spatial resolution and the recognized flaws are documented as result of the training. This procedure can also be used for examination of candidates. The virtual digital images produced are equivalent to real exposures. The image interpretation and documentation after virtual exposures is equivalent to interpretation and documentation of practical exposures and, therefore, the virtual radiography can be used in lieu of practical training or practical examination.

6. QUALIFICATION EXAMINATION

6.1. NUMBER OF QUESTIONS FOR GENERAL AND SPECIFIC EXAMINATION

ISO 9712:2012 specifies the conditions for the qualification examination. For the complete information the standard shall be referenced.

Here is a summary of the most important requirements for level 1 and 2 examination:

- The Certification Body shall define and publish the maximum amount of time allowed for the completion of each examination.
- The written tests of the "general" and "specific" examinations are assessed by comparing the replies given by the candidate against answer keys approved by the certification body.
- Each correct reply scores 1 point and the mark attributed to the test is equal to the sum of points obtained. For the final calculation, the mark of each test is expressed as a percentage.
- The candidate shall be required, as a minimum, to give answers to the number of multiple choice questions shown in Table 4 of ISO 9712:2012.
- Where not otherwise addressed by national regulations, there shall be an additional examination on radiation safety for the radiographic test method.
- The **general part shall consist of 40 multiple choice questions** independently on the level and training hours for RT-D, and RT-S.
- The specific examination shall include only questions selected from the examination question databank of the certification body, or that of the authorised qualifying body that has been approved by the certifying body.
- During the **specific examination**, the candidate shall be required to give answers to at least **20 multiple-choice questions**, including questions involving calculations, written procedures and questions on codes, standards and specifications.
- If the **specific examination covers two or more sectors**, the minimum number of questions **shall be at least 30 (level 1 and 2)**, evenly spread between the sectors concerned.

In conclusion of these requirements the general examination shall consist of 40 questions and the specific one for more than one industrial sector shall consist of 30 questions for RT-D, or RT-S (level 1 and 2). See also Table 11.

Here is a summary of the most important requirements for level 3 examination:

For level 3 the ISO 9712:2012 gives guidance in clause 8.3. The candidate needs additionally a basic examination which is widely independent on the method to examine. Four test methods shall be covered. One of the methods should be RT-F. 60 questions shall be answered for the four test methods. 35 questions shall cover the knowledge in material science and process technology as well as certification systems. He needs furthermore the level 2 certificate or at least the successfully passed practical level 2 examination. See for more details in ISO 9712:2012.

The main examination consists of **30 general questions, 20 specific questions on application of the main method** and the "**drafting of one or more NDT procedures in the relevant sector (level 3)**". See also Table 11.

ISO 9712:2012 shall be followed for examination, certification and recertification (see clause 8.4, 8.5and 9 in ISO 9712).

6.2. PRACTICAL EXAMINATION AND NUMBER OF TEST PIECES

The practical examinations shall be conducted for the sectors welding, castings and tubes and pipes, if not otherwise specified by the certification body, or agreed with the testing candidate. Practical examinations shall be performed with at least two different digital detectors, as e.g. CR and DDA for RT-D. See also Table 10 and 12.

For RT-S the practical examinations can be performed with the same inspection device, as e.g. DDA, X-ray intensifier or fluoroscope. The industrial sector to select should be “Pre and in-service testing”, considering the product sectors welds and castings. Optionally, “tube and pipes” is recommended as a further product sector. See also Table 10 and 12.

At least two different test specimens for practical examination in level 1 and 2 are required, one weld and one casting, which shall be certified by the certification board as test specimens for examination in RT-D and/or RT-S. Test specimens have to be stored under confidential conditions and shall not be used for prior training. See also Table 12.

For radiographic examination, level 1 and level 1 candidates shall radiograph at least two volumes - except for level 1 candidates holding level 1 certification, where at least one volume is to be radiographed.

24 digital radiographs are required for evaluation by the examined candidates in RT-D, Module 1 and 2, level 1 and 2. They shall consist of digital radiographs of welds (8), castings (8) and tube and pipes (8). If “tube and pipes” is not considered for certification, also 24 digital radiographs are required for evaluation by the examined candidates. They shall consist of digital radiographs of welds (12) and castings (12).

RT-S practical examination shall include “welds and castings”. “Tube and pipes” is optional.

For level 2, written instruction for level 1 shall be written in the relevant product sectors during examination.

For certification in level 1 or 2 one practical exposure (weld or casting) can be performed by a virtual simulation tool upon agreement of the certification board and its auditing organization. Candidates shall perform at least one practical exposure in the examination.

For certification in level 3 the candidates have to prove they have been successful in a level 2 practical examination and they have to write a procedure in the relevant product sectors for examination. See ISO 9712:2012 for more detail on level 3 examination.

Handling and storage of test specimens shall consider the requirements of ISO TR 25108 [9]. The position and characterization of all real or artificial discontinuities, relevant to the NDT method/technique within each specimen should be recorded on a master plot.

6.3. REQUIRED GRADE OF EXAMINATION

The criterions for accepting the examination grading are specified in clause 8.2. and 8.3 and in Annex D of ISO 9712:2012. The standard requires as follows:

Levels 1 and 2:

To be eligible for certification the candidate shall obtain a minimum grade of 70 % in each part of the examination (general, specific and practical). In addition, for the practical examination, a minimum grade of 70 % shall be obtained for each specimen tested, and for the NDT instruction as applicable.

For the level 2 candidates, the specimen for which the instruction is produced shall be graded with an overall grade of 100. The other specimens (without instruction) shall be graded with an overall grade of 85. See ISO 9712:2012 for details.

The requirements of ISO 9712:2012 shall be strictly fulfilled for certification.

Level 3:

All candidates for level 3 certification in any NDT method shall have successfully completed (with a grade of ≥ 70 %) the practical examination for level 2 in the relevant sector and method, except for the drafting of NDT instructions for level 1. A candidate who is level 2 in the same NDT method and product sector, or has successfully passed a level 2 practical examination for the NDT method in an industrial sector as defined in Annex A, is exempt from passing again the level 2 practical examination. This exemption is only valid for the product sectors covered by the industrial sector concerned and, in any other circumstances; the relevant sector is the sector in which the candidate seeks level 3 certification.

Level 3 personnel have at least to finalize a basic training in at least four NDT methods and to pass a "basic examination". The written examination shall assess the candidate's knowledge of the main method subjects using the minimum required number of multiple-choice questions. The grading of the basic and main method examinations shall be done separately. To be eligible for certification, a candidate shall pass both the basic and main method examinations.

In order to pass the basic examination, the candidate shall obtain a minimum grade of 70 % in each of the examination parts.

Level 3 personnel have to pass the examination in the main method too. In order to pass the main method examination, the candidate shall obtain a minimum grade of 70 % in each of the parts.

Level 3 candidates have to pass a procedure writing examination, which is evaluated as described in ISO 9712:2012.

The requirements of ISO 9712:2012 shall be strictly fulfilled for certification.

7. CERTIFICATION

7.1. EMPLOYERS RESPONSIBILITY AND EXPERIENCE TIMES

Certification in RT-D can be finalized after training, successfully passed examination with correct access conditions (e.g. RT-F level 2 certificate for RT-D module 2 training with examination) and proven experience times.

The certification is only valid if the employer confirms as stated in ISO 9712:2012:

"The employer shall introduce the candidate to the certification body or the authorised qualifying body and document the validity of the personal information provided. This information shall include the declaration of education, training and experience and visual acuity needed to determine the eligibility of the candidate. If the candidate is unemployed or self-employed, the declaration of education, training and experience shall be attested to by at least one independent party acceptable to the certification body." For more detail see clause 5.5 in ISO 9712:2012.

Clause 7 of ISO 9712:2012 describes the eligibility for certification. It is states: "The candidate shall fulfill the minimum requirements of vision and training prior to the qualification examination and shall fulfill the minimum requirements for industrial experience prior to certification."

The required experience time shall be confirmed by the employer in written form and send to the certification board. Table 8 informs about the required experience times prior to the certification.

RT-D certification after passing RT-D examination is possible for RT-F certified personnel, if the experience times of RT-F level 1 and 2 are recognized. It is recommended to require additional 1/3 of the RT-D experience times. See Tables 8. For possible reduction of experiences times see also clause 7.3.3 in ISO 9712:2012.

TABLE 8. EXPERIENCE REQUIREMENT FOR RT CERTIFICATION

NDT Method RT	Experience in months		
Techniques F, D, S	Level 1	Level 2	Level 3
RT-F, RT-D, RT-S	3	9	18
RT-D, with existing certification in RT-F in the same level and same sectors[a)]	1	3	6

[a)]The numbers are recommended minimum numbers of months, but may be modified by the national certification bodies.

- For certification in level 2 the experience time of level 1 and 2 is required
- For certification in level 3 the experience time of level 2 and 3 is required and a qualification of a technical school or 2 years study time at a college or university, otherwise the required experience time doubles.
- More details and possible reductions; *see ISO 9712:2012.*

7.2. VISION REQUIREMENTS

In modification to ISO 9712:2012 the following requirements shall be fulfilled:

The candidate shall provide documentary evidence of satisfactory vision in accordance with the following requirements:

(a) Near vision acuity shall permit reading a minimum of Jaeger number 1 or Times Roman N 4.5 or equivalent letters (having a height of 1,6 mm) at not less than 30 cm with one or both eyes, either corrected or uncorrected.

(b) Colour vision is less important for reading of digital radiographic images. Colour vision shall be sufficient that the candidate can distinguish and differentiate coarse contrast between the colours and fine contrast shades of grey used in RT-D method concerned as specified by the employer.

Subsequent to certification, the tests of visual acuity shall be carried out annually and be verified by the employer.

8. SUMMARY AND RECOMMENDATIONS

The development of the following new training modules for Digital Industrial Radiology is proposed:

1. Digital Industrial Radiology (**RT-D**) Training Module 1 , no prior certification is needed
2. Digital Industrial Radiology (**RT-D**) Training Module 2, for RT-F certified personnel
3. Digital Industrial Radioscopy (**RT-S**), no prior certification is needed

The required training hours are as follows:

TABLE 9. REQUIRED TRAINING HOURS AND ACCESS CONDITION FOR RT_D/RT-S TRAINING MODULES

	RT-F certificates required	Level 1 hours	Level 2 hours	Level 3 hours
RT-D module 1	No	40	80	40
RT-D module 2	Yes	32	60[a)] 60 hours are for direct access to level 2 acceptable	32 Direct access to level 3 requires 80 hours
RT-S	No	32	48	32

[a)]May be reduced to 56 hours if 32 hours have been trained for level 1.

- *For level 2 certification, the level 1 training hours and the level 2 training hours have be summarized for RT-D module 1 and RT-S.*
- *For level 3 certification, the training hours for level 1 and 2 and level 3 have to be summarized for RT-D module 1 and RT-S.*
- *See ISO 9712:2012 for more detail on level 3.*

It is recommended to follow the training syllabi as shown in Tables 5-7.

Required equipment for RT-D:

TABLE 10. REQUIRED HARDWARE FOR RT-D/RT-S TRAINING (WITHOUT VIRTUAL TRAINING OPTION)

	X-Ray source and/or Gamma source	Radiation measure technique and bunker or X-Ray cabin	Computed radiography	Digital Detector Array	X-ray image intensifier	X-ray fluoroscope	Personal computer	Viewer software
RT-D Training module 1	X	X	X	X			X	X
RT-D Training module 2	X	X	X	X			X	X
RT-S	X	X		X or →	X or →	X	X	X

- Optionally, for RT-D Training Modules 1 and 2 film digitization technology is recommended.
- RT-D training can also be performed, if only CR **or** DDA technology is available and one missing technology is trained with **virtual** training software.
- ISO/ TR 25108 [9] shall be considered. It requires furthermore:
    - a range of image quality indicators (IQI);
    - lead letters and numbers;
    - masking materials as blocking-off compounds and/or liquids;
    - copper and lead filters;
    - radiation monitor;
    - stepped blocks for making exposure curves;
    - caliper or other device for measuring material thickness

Required number of examination questions for RT-D training:

TABLE 11. REQUIRED NUMBER OF EXAMINATION QUESTIONS FOR RT-D/RT-S EXAMINATION

	General level 1+2	Specific level 1+2	Method level 3	Application level 3
RT-D	40	30	30	20
RT-S	40	30	30	20

For certification in level 3 additionally a

- basic examination in at least four main NDT methods (60 questions) is required and (35 questions) in material science, process technology and certification systems as well as the practical level 2 examination.
- Drafting of one or more NDT procedures in the relevant sector. The applicable codes, standards, specifications and procedures shall be available to the candidate.
- See ISO 9712:2012 for more detail on level 3.

Required number of practical tests for examination:

TABLE 12. REQUIRED PRACTICAL EXAMINATION TESTS FOR RT-D/RT-S EXAMINATION

	Practical exposure of weldments	Practical exposure of castings	Viewing and evaluation of digital radiographs of welds	Viewing and evaluation of digital radiographs of castings	Viewing and evaluation of digital radiographs of corroded pipes
RT-D	Level 1 + 2 1 exposure	Level 1 + 2 1 exposure	Level 2 8 dig. images	Level 2 8 dig. images	Level 2 8 dig. images
RT-S	Level 1 + 2 1 exposure	Level 1 + 2 1 exposure	Level 2 12 dig. images	Level 2 12 dig. images	-

- The Table 12 is related to the certification of an industrial sector (e.g. “Pre- and in-service testing”). The certification board may request 1 additional exposure of a tube or pipe for RT-D and increase the number of digital images for the examination to 12 per product sector, if certifying of separate product sectors is required.
- For certification in level 2 only one practical exposure needs to be performed for certified level 1 personnel in the level 2 practical examination.
- For certification in level 2 the candidates have to write an instruction for level 1 operators in the relevant product sectors for examination.
- For certification in level 1 or 2 one practical exposure (weld or casting) can be performed by a virtual simulation tool upon agreement of the certification board and its auditing organization. Candidates shall perform at least one practical exposure in the examination.
- For certification in level 3 the candidates have to
    - prove the successful level 2 practical examination and to
    - write a procedure in the relevant product sectors for examination.
- *See ISO 9712:2012 for more detail on level 3 examination.*

Required experience times:

Required experience times are discussed in clause 7.1 and listed in Table 8. It is recommended to require additional 1/3 of the RT-D module 1 experience times for RT-F certified personnel for the RT-D certification (Table 8). For certification in level 2 the experience time of level 1 and 2 is required. For certification in level 3 the experience time of level 2 and 3 is required. Reductions are possible; see ISO 9712:2012 for more detail.

9. CONCLUSION ON PRIORITY FOR INTRODUCTION OF RT-D TRAINING MODULES

The following priority is recommended for the order of training courses to be developed by IAEA:

- **RT-D module 2,** level 2: Training of certified RT-F 2 and/or RT-F 3 personnel in RT-D, level 2, seems to be of highest interest in the NDT community for training and certification of radiographic operators changing from film radiography to digital radiography level 2 ("film replacement"). The training course allows the direct access to RT-D level 2 without level 1 training and examination. RT-D level 3 personnel need the pre-knowledge of the level 2 training course and the RT-D, level 2, practical examination for certification.

- **RT-D module 2** (level 1 and level 2) training is of interest for industry in the long term, since companies will need also more level 1 operators in the future, after achieving a minimum number of level 2 operators.

- **RT-S** (level 1 and level 2) is of importance for industries with serial part production (e.g. fine castings). In most cases complex radioscopic devices need to be operated. The training classes should be combined with training of the specific devices, installed by the companies. Such training is typically conducted together with the manufacturer and/or the final user of the equipment.

- **RT-CT**: Computed Tomography is currently not widely applied in industry. CT devices are relatively complex units and need specific training on the CT equipment by the manufacturer. It is not likely that operators will already be trained in RT-F. Therefore, a specialized CT training module should be developed together with manufacturers on the basis of an extended RT-S training course.
- Additional training is required in 3D-image processing and measurement tools in 3 dimensions. The RT-S course supplies the basic knowledge on CT, but no specialized training of manufacturer specific devices. No need is seen to extend the training activities for CT currently and it is recommended that this training should be equipment specific training rather than general training.

- **RT-D**: General RT-D module 1 training, without prior RT-F training, is likely to be required in the longer term if film radiography loses its relative importance with respect to RT-D. Therefore, the full RT-D training course at this stage is not recommended as a replacement for RT-F training. E.g., the German Society for NDT and its Radiology Committee has decided to postpone the development of a complete RT-D module 1 training course.
- It is recommended instead, to replace the RT-D, level 2 training course with a new RT, level 3 training course with integrated level 3 training in RT-F and RT-D. The German society has finalized a new RT, level 3 course (80 hours), which integrates film (RT-F) and digital detectors (RT-D) including CT as well. Initial discussions with ASNT indicate that ASNT will also consider the development of a common level 3 training course with film and digital techniques integrated. As a result, it is recommended to IAEA and Member States to consider an integrated level 3 training course (RT, level 3) instead of a separated RT-D, level 3 training course.

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ABBREVIATIONS

RT	Radiographic testing
RT-D	Radiographic testing – Digital technique
RT-F	Radiographic testing – Film Technique
RT-S	Radiographic testing – Radioscopy with training time ≥ 50% of level 2 of RT-D
RT-CT	Radiographic testing – Computed Tomography
UT	Ultrasonic testing
VT	Visual testing
PT	Penetrant testing
MT	Magnetic testing
CR	Computed Radiography (also known as RT with phosphor imaging plates)
DDA	Digital Detector Array (also known as flat panel detector)
LDA	Line Detector Array
DIR	Digital Industrial Radiography
NDT	Non Destructive Testing
DGZfP	German Society for NDT
ISNT	Indian Society of NDT
ICNDT	International Committee for NDT
ISO	International Standardization Organization
IQI	Image Quality Indicator
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers

APPENDIX I. AVAILABLE IAEA TRAINING LECTURES FOR RT-D MODULE 2

The IAEA training on digital industrial radiology is basically designed as a training course for level 2 and may also be used for level 3 training to be conducted within a week. It needs to be updated considering the recently published standards on RT-D since 2010 and the corresponding exercises.

The PowerPoint lectures and the training booklet [9, 10] were developed for IAEA in 2009. The training book and the presentations cover the RT-D Module 2, level 2, and training with direct access to level 2 for RT-F level 2 certified personnel.

The training booklet has the following Table of content:

L 04 Standards II

L 05 Fundamentals of Digital Image Processing

L 06 X-ray Sensitive Detectors I

L 07 X-ray Sensitive Detectors II

Example of a testing record

Written exercises are available (developed for one week training at 4 days after setup of computers at first day)

- Image Acquisition with Computed Radiography
- Contrast Optimization and Segmentation
- Measurement of Distances and Calibration

Software is available

- Image viewer software **ISee** (free demo licence [11]) and pen-drive or DVD with digital images
- Simulation software **aRTist** (licensed for limited time [12]) can be distributed for training issues.

Hardware is available: e.g. low budget fluoroscope (IAEA construction guidebook under reference ‘’ Design, Development and Optimization of a low-cost System for Digital Industrial Radiology ‘’ Radiation Technology Reports n°2, ISBN number: 978-92-0-129310-7).

Following Updates are required

- Measurements of exposure diagrams for CR
- DDA practice, measurement of CNR for plate holes
- DDA quality assurance ASTM E 2737
- Exercise with standard practice of ISO 17636-2
- Exercise with standard practice ASTM BPVC S. V article 2
- Exercise with viewing of digital reference catalogues

INFORMATIVE REFERENCE TO ISO 9712:2012 ON REQUIRED TRAINING HOURS

Table A1.1 shows the required number of training hours and the conditions for the reduction of the training time, down to 50%. RT is split in RT-F and RT-D in extension to the current Table 2 of ISO 9712:2012. All extensions are highlighted.

TABLE A1.1. MINIMUM TRAINING HOURS AS REQUIRED BY ISO 9712:2012 (EQUIVALENT TO TECDOC-628/REV.2 FOR RT-F), WITH EXTENSIONS BY DIFFERENT RT TECHNIQUES

NDT Method		Level 1 hours	Level 2 hours	Level 3 hours
AT		40	64	48
ET		40	48	48
LT				
	B - pressure method	24	32	32
	C – Tracer gas method	24	40	40
MT		16	24	24
PT		16	24	24
ST		16	24	20
TT		40	80	40
RT	RT-F	40	80	40
	[a,b]RT-D	40	80	40
UT		40	80	40
VT		16	24	24

- [a] Training duration may be reduced by up to 50 %:
  - for RT-D training of personnel certified in the same or higher RT-F level
  - in only one technique as training using only Radioscopy (RT-S) is sought

[b] **60** hours are required for direct access to level 2 without level 1 training and examination of personnel certified in the same or higher RT-F level.

- NOTE: For RT, training hours do not include radiation safety training.

INFORMATIVE BREAK DOWN OF TRAINING HOURS FOR RT-D/S

The Tables 5-6 show the coarse break down of training hours. The following Tables A1.2 – A1.4 show a proposed fine-tuned breakdown for the training hours. This may be modified depending on the need of the national training centers.

TABLE A1.2. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 1

Syllabus for Digital Industrial Radiology RT-D Module 1

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
General knowledge NDT	**1**	**0**	**2.5**	**0**	**0**	**0**
Origin of discontinuities	0.25		0.25		a)	
Need for NDT	0.25		0.25		a)	
NDT methods – Principles, advantages, applications and limitations	0.25		1		a)	
Materials and processes	0.25		1		a)	
Physical principles of X-ray technique	**2**	**0.25**	**4.75**	**0**	**2.45**	**0**
Structure of the atom	0.25		0.25			
Atomic model			0.5			
Electromagnetic spectrum	0.25		0.25			
Sources of radiation, their properties, X-Rays, Gamma rays	0.25		0.25			
Neutrons					0.2	
X-Ray and Gamma ray spectrum			0.25		0.2	
Essential radiographic parameters (voltage, current, activity,…)	0.5		0.5			
Filters			0.25		0.2	
Focal spot			0.25		0.2	
General mechanism of interactions	0.25				0.5	
Photoelectric effect			0.25			
Compton effect			0.5			
Pair production			0.25			
HVL, TVL and attenuation law	0.5	0.25	0.5		0.2	
Hardening of radiation, filtering, collimation			0.5		0.2	
Scattered radiation and build-up factor			0.25		0.2	
Fluorescence					0.2	
Attenuation of neutrons and electrons					0.25	
Radiation contrast, noise	**1.5**	**1**	**3**	**3.5**	**1.2**	**0**
Contrast and noise	0.5	0.5				
Specific contrast			0.5	0.5	0.2	
Scatter influence	0.5	0.5	0.5	0.5	0.2	
Signal-to-noise ratio			1	1	0.3	
Contrast-to-noise ratio			0.5	0.5	0.2	
Basic spatial resolution			0.25	0.5	0.2	
Pixel size	0.5					
Normalized SNR_N			0.25	0.5	0.1	
b) **Geometrical projection conditions**	**1.5**	**2**	**1**	**1.5**	**1**	**0.5**
Geometrical and inherent unsharpness	0.5	0.5	0.25	0.5	0.2	
Geometrical magnification		0.5				
Effect of magnification	0.5	0.5	0.2	0.5	0.2	
Optimum magnification			0.2	0.5	0.2	0.3
Difference between Radiography and Radioscopy			0.1		0.2	0.2
Law of the squared distances	0.5	0.5	0.25		0.2	

Syllabus for Digital Industrial Radiology RT-D Module 1 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Optimisation of image quality	**1**	**1**	**1.75**	**1.5**	**1.5**	**0**
Compensation principles	0.5		0.25			
Contrast vs. SNR		0.2	0.4	0.5	0.2	
Basic spatial resolution vs. SNR		0.3	0.4	0.5	0.2	
Local unsharpness vs. SNR			0.2		0.3	
Scatter protection	0.5	0.5	0.25	0.25	0.25	
Maximum/optimum X-ray voltage			0.25	0.25	0.25	
Image quality indicators, standards	**1**	**2**	**1**	**0**	**0.5**	**0.5**
Wire type	0.25	0.25				
Step hole type	0.25	0.5				
Plate hole type	0.25	0.5				
Duplex wire type	0.25	0.5				
Measurement of basic spatial resolution			0.25			
Converging line pairs			0.25			
Line pairs gauges (MTF)					0.5	0.5
Standards (see clause Table 2)			0.5			
Equipment and work – Radiation sources	**2**	**2**	**3.5**	**2**	**2.5**	**0.5**
X-ray standard sources	0.5	0.5	0.25	0.5	0.2	
X-ray special sources			1		0.5	
X-ray - Generation of high voltage			0.75		0.3	
X-ray - Cooling			0.25		0.1	
X-ray - Handling	0.5	0.25	0.25		0.1	
X-ray -Parameters: kV, mA, spot size		0.5	0.5	1	0.2	
X-ray - Measurement of parameters					0.5	0.5
Gamma sources - Handling and projector	0.5	0.5		0.5	0.2	
Gamma sources - Special design			0.25		0.2	
Gamma sources -Parameters: isotope, activity, source size	0.5	0.25	0.25		0.2	
Equipment and work – detectors : CR, imaging plates	**2**	**2**	**1.75**	**2.25**	**1.5**	**0.5**
Phosphor imaging plates – Introduction and design	1	0.5				
Imaging plate and CR scanner	0.5	0.5	0.5	0.5	0.2	
CR system and classification			0.5		0.2	
Quality assurance (phantom)		0.5	0.25	0.5	0.2	
Exposure conditions and diagrams			0.5	1	0.2	0.5
Handling	0.5	0.5		0.25	0.2	
System selection					0.5	
Equipment and work – detectors : DDAs	2	2	2	2	2	0
Introduction and design	1	0.5	1		0.5	
Indirect converting						
Direct converting						
CCD, amorph. Si, CMOS						
Detector calibration			0.5	0.5	0.5	
Quality assurance			0.5	0.5	0.25	
Exposure conditions	0.5	1		0.5	0.25	
Handling	0.5	0.5		0.5		
System selection					0.5	
Equipment and work – detectors : LDAs	**0**	**0**	**0.5**	**0**	**1**	**0**
Introduction and design			0.5		0.5	
Application areas					0.1	

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Comparison to DDAs					0.1	
Quality assurance						
Exposure conditions					0.1	
Handling						
System selection					0.2	
Equipment and work – detectors : intensifiers, fluoroscope	**0**	**0**	**1.25**	**0.25**	**1**	**0**
Introduction and design			0.5		0.1	
Application areas			0.25		0.1	
Comparison to DDAs			0.25		0.1	
Quality assurance			0.25		0.1	
Exposure conditions				0.25	0.1	
Handling						
System selection					0.5	
Equipment and work – detectors : film digitization	**0**	**0**	**0.5**	**0**	**0.5**	**0**
Scanner design (camera based, line scanners, laser scanners)				0.25		0.1
Quality assurance (EPRI test film)				0.25		0.1
Handling, archiving						0.1
System selection						0.1
Classification						0.1
Data acquisition, detector calibration	0	0	2	2	1	1
A/D interface			0.25		0.2	
Computer structure (Processor, memory, bus, disk, Load and save of digital images, image formats)			0.25	0.5	0.3	
Image integration (on-chip, in memory, optimum gain and latitude settings, accumulation vs. integration)			1.5	1.5	0.5	1
Digital image processing (total)	**2**	**2.75**	**7**	**7**	**3.1**	**2.5**
Image structure, quantisation (bits and bytes)	0.25		0.5		0.25	
Basic operation (picture element – pixel, gray value)	0.75	1	0.5		0.25	
Point operations (contrast, brightness, gamma correction, histogram, LUT)	1	1	1	1	0.25	0.5
Matrix operations, filter (smoothing, improvement of SNR, high pass, gradient, edge enhancement, line extraction, median)			3	3	1.5	1
Measurement tools (calibration, line profile, measurement of flaw, length, measurement of areas and depth)		0.75	1	2	0.35	1
Correction of raw data (linearization, LUT correction, bad pixel interpolation)			1	1	0.5	
Standards	1	0	3	1.5	3	0
Guides	0.5		1		0.5	
Qualification of sources			1	0.5	0.5	
General qualification of detectors					1	
User qualification of detectors	0.5		1	1	1	
See Table 2						
Defectology, digital catalogues	**0.5**	**0.5**	**1**	**2.5**	**0.75**	**1**

Syllabus for Digital Industrial Radiology RT-D Module 1 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
- General welding (ISO 6520) and casting defects (ASTM casting catalogues)	0.5	0.5	0.5	0.5	0.25	
- Evaluation of welding: IIW catalogue - ISO 5817			0.5	1	0.25	0.5
- Evaluation of casting: ASTM catalogues				1	0.25	0.5
- corrosion						
Automated image interpretation	**0**	**0**	**1**	**1**	**1**	**0**
- Principles			0.25		0.3	
- Binarisation			0.5	0.5	0.4	
- Measurement of dimensions			0.25	0.5	0.3	
[b)] **Special techniques, computed tomography**	**0**	**0**	**1**	**1**	**1.5**	**0.5**
- Stereoradiography			0.5		0.25	
- Laminography					0.25	
- Computed tomography			0.5	1	0.5	0.5
- Inspection geometry						
- 2D vs. 3D						
- Reconstruction principles						
- Filtered backprojection						
- Applications						
- Requirements and limit of method						
- Special CT techniques					0.5	
Applications, standard practices and evaluation	**2**	**3**	**2.5**	**6**	**2**	**2.5**
- Welds (standard practices with different exposure geometries, interpretation of digital images, digital processing of images, evaluation of flaws with dimensions measurement, written instruction/procedure)	1	1	1	3	1	1

Syllabus for Digital Industrial Radiology RT-D Module 1 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
- Castings (standard practices with different exposure geometries, interpretation of digital images, digital processing of images, evaluation of flaws with dimensions measurement, use of catalogues, written instruction/procedure)	1	1	1	2	0.5	1
- Corrosion wall thickness measurement (tangential RT, double wall RT, calibration of digital images, measurement of thickness, written instruction/procedure)		1		1		0.5
- Others…			0.5		0.5	
Written procedure/ instructions	**0**	**0**	**1**	**2**	**0**	**2**
Welds			0.5	0.75		0.75
Castings			0.5	0.75		0.75
Corrosion wall thickness measurement				0.5		0.5
[c] **Radiation protection** Extra training course depending on national regulations recommended	1	1	1	1	1	0
Total	**20.5**	**20**	**43**	**37**	**28.5**	**11.5**
	40		**80**		**40**	

[a] In addition to the above 40 hours a general knowledge common core course for level 3 (applicable to all NDT methods) is recommended, which shall be successfully completed only once.

[b] More hours are recommended for RT-CT related training.

[c] National laws and regulations are to be considered for training on radiation safety and handling of radiation sources. Radiation safety may be trained in separated courses, or training hours should be considered to be additional to those of the syllabus requirements (see TECDOC-628/Rev.2).

TABLE A1.3. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 2

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
General knowledge NDT	**0**	**0**	**0**	**0**	**0**	**0**
- Origin of discontinuities					a)	
- Need for NDT					a)	
- NDT methods, principles, advantages, applications and limitations					a)	
- Materials and processes					a)	
Physical principles of X-ray technique	0.9	0.2	1	0	1.4	0
- Structure of the atom	0.1		0.1			
- Atomic model			0.1			
- Electromagnetic spectrum			0.1			
- Sources of radiation, their properties, X-rays, gamma rays	0.25		0.1			
- Neutrons					0.2	
- X-ray and gamma ray spectrum			0.1		0.1	
- Essential radiographic parameters (voltage, current, activity)	0.1		0.1		0.1	
- Filters			0.1		0.1	
- Focal spot			0.1		0.1	
- General mechanism of interactions (photoelectric effect, Compton effect, pair production)	0.25		0.2		0.3	
- HVL, TVL and attenuation law	0.1				0.1	
- Hardening of radiation, filtering, collimation	0.1	0.2			0.1	
- Scattered radiation and build-up factor					0.1	
- Fluorescence					0.1	
- Attenuation of neutrons and electrons					0.1	
Radiation contrast, noise	**0.9**	**0**	**1.5**	**1.5**	**1.2**	**0**
- Contrast and noise	0.5					
- Specific contrast			0.25		0.2	
- Scatter influence	0.15		0.25		0.2	
- Signal-to noise ratio			0.25	0.5	0.3	
- Contrast-to noise ratio			0.25	0.25	0.2	
- Basic spatial resolution			0.25	0.5	0.2	
- Pixel size	0.25					
- Normalized SNR_N			0.25	0.25	0.1	

TABLE A1.3. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 2 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
b) Geometrical projection conditions	**1**	**1**	**0.5**	**0**	**1**	**0**
- Geometrical and inherent unsharpness			0.2		0.2	
- Geometrical magnification	0.25	0.5				
- Effect of magnification	0.25	0.5	0.2		0.2	
- Optimum magnification					0.2	
- Difference between radiography and radioscopy					0.2	
- Law of the squared distances	0.5		0.1		0.2	
Optimisation of image quality	**1**	**0**	**1**	**1**	**1**	**0**
- Compensation principles	0.5					
- Contrast vs. SNR			0.3	0.5	0.2	
- Basic spatial resolution			0.3	0.5	0.2	
- Local unsharpness vs. SNR					0.2	
- Scatter protection	0.5		0.2		0.2	
- Maximum/optimum X-ray voltage			0.2		0.2	
Image quality indicators, standards	**1**	**1**	**0**	**0**	**0**	**0**
- Wire type	0.25	0.25				
- Step hole type	0.25	0.25				
- Plate hole type	0.25	0.25				
- Duplex wire type	0.25	0.25				
- Measurement of basic spatial resolution						
- Converging line pairs						
- Line pair gauges (MTF)						
- Standards (see clause Table 2)						
Equipment and work – Radiation sources	**1**	**2**	**4**	**1**	**2**	**0**
- X-Ray sources						
o Standard sources	0.25	0.5	0.25		0.1	
o Special source			1		0.5	
o Generation of high voltage			0.75		0.1	
o Cooling			0.25		0.1	
o Handling	0.25	0.5	0.25		0.1	
o Parameters : kV, mA, spot size		0.5	0.5	0.5	0.2	
o Measurement of parameters					0.5	
- Gamma sources and containers						
o Handling and projector	0.25	0.5	0.25	0.5	0.1	
o Special design			0.25		0.1	
o Parameters: isotope, activity, source size	0.25		0.5		0.2	

TABLE A1.3. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 2 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Equipment and work – detectors : CR, imaging plates	**1.5**	**2**	**2**	**2**	**1**	**1**
- Phosphor imaging plates, introduction and design	0.5	0.5				
- Imaging plate and CR scanner	0.5	0.75	0.5	0.5	0.1	
- CR system and classification			0.5		0.1	
- Quality assurance (phantom)			0.25	0.25	0.2	0.2
- Exposure conditions and diagrams			0.5	1	0.2	0.5
- Handling	0.5	0.75	0.25	0.25	0.2	
- System selection					0.2	0.3
Equipment and work – detectors : DDAs	**1.5**	**2**	**2**	**2**	**1.5**	**0.5**
- Digital Detector Arrays (DDA)-Introduction and design	0.5	0.5	1		0.5	
o Indirect converting						
o Direct converting						
o CCD, amorph, Si, CMOS						
- Detector calibration		0.5	0.5	0.5	0.3	
- Quality assurance			0.5	0.5	0.1	0.25
- Exposure conditions	0.5	0.5		0.5		0.25
- Handling	0.5	0.5		0.5	0.1	
- System selection					0.5	
Equipment and work – detectors : LDAs	**0**	**0**	**0.5**	**0**	**0.5**	**0**
- Line Detector Arrays (LDAs)-Introduction and design			0.5		0.1	
- Application areas					0.1	
- Comparison to DDAs					0.1	
- Quality assurance					0.1	
- Exposure conditions						
- Handling						
- System selection					0.1	

TABLE A1.3. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 2 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Equipment and work – detectors : intensifiers, fluoroscope	**0.5**	**0**	**0.5**	**1**	**0.5**	**0**
- Introduction and design	0.5		0.25		0.1	
- Application areas				0.25	0.1	
- Quality assurance				0.25	0.1	
- Exposure conditions				0.25		
- Handling				0.25		
- System selection					0.1	
- Comparison to DDAs			0.25		0.1	
Equipment and work – detectors : film digitization	**0**	**0**	**0.5**	**0**	**0**	**0**
- Scanner design			0.25			
o Camera based						
o Line scanners						
o Laser scanners						
- Quality assurance (EPRI test film)			0.25			
- Handling, archiving						
- System selection						
- Classification						
Data acquisition, detector calibration	**0**	**0**	**1**	**1**	**1**	**0**
- A/D interface			0.25		0.3	
- Computer structure			0.25		0.2	
o Processor, memory, bus, disk						
o Load and save of digital images						
o Image formats						
- Image integration			0.5	1	0.5	
o On chip integration						
o In memory integration						
o Optimum gain and latitude settings						
o Accumulation vs. integration						
Digital image processing	**2.5**	**2**	**6**	**4**	**3**	**3**
- Image structure, quantisation (bits and bytes)	0.5		0.5		0.25	
- Basic operation (picture element-pixel, gray value)	1	1	0.5		0.25	

TABLE A1.3. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 2 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
- Point operations (contrast, brightness, gamma correction, histogram, LUT)	1	1	0.5	0.5	0.5	0.5
- Matrix operations, filter (smoothing, improvement of SNR, high pass, gradient, edge enhancement, line extraction, median)			2.5	1	1.5	1.5
- Measurement tools (calibration, line profile, measurement of flaw length, areas, depth)			1	1.5		1
- Correction of raw data (linearisation, LUT correction, bad pixel interpolation)			1	1	0.5	
Standards	**0.5**	**0.5**	**3**	**3**	**2**	**0**
- Guides					0.5	
- Qualification of sources			0.5	0.5	0.5	
- General qualification of detectors			0.5		0.5	
- User qualification of detectors	0.5	0.5	2	2.5	0.5	
- See Table 2						
Defectology, digital catalogues	**0.25**	**0.75**	**1**	**1**	**0.5**	**0.5**
- General welding (ISO 6520) and casting defects (ASTM casting catalogues)		0.5	0.5		0.25	
- Evaluation of welding: IIW catalogue ISO 5817				0.5		0.25
- Evaluation of casting: ASTM catalogues		0.25		0.5		0.25
- Corrosion	0.25		0.5		0.25	

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Automated image interpretation	0	0	1	1	0.5	0.5
- Principles			0.5		0.5	
- Binarisation			0.25	0.5		0.25
- Measurement of dimensions			0.25	0.5		0.25
b) Special techniques, computed tomography	**0**	**0**	**1**	**1**	**1**	**0**
- Stereo radiography			0.5	0.25	0.25	
- Laminography					0.25	
o Computed tomography			0.5	0.75	0.25	b)
o Inspection geometry						b)
o 2D vs. 3D						b)
o Reconstruction principles						b)
o Filtered backprojection						b)
o Applications						b)
o Requirements and limit of method						b)
- Special CT techniques					0.25	b)
Applications, standard practices and evaluation	**3**	**3**	**3.5**	**5.5**	**2.5**	**3**
- Welds (standard practices with different exposure geometries, interpretation of digital images, digital processing of images, evaluation of flaws, measurement of flaw dimensions, written instruction/procedure)	1	1	1	1.5	1	1
- Castings (standard practices with different exposure geometries, interpretation of digital images, digital processing of images, evaluation of flaws, use of catalogues, measurement of flaw dimensions, written instruction/procedure)	1	1	1	1.5	0.5	1
- Corrosion wall thickness measurement (tangential RT, double wall RT, calibration of digital images, measurement of thickness, written instruction/procedure)	1	1	0.5	1.5	0.5	1
- Others…			1	1	0.5	

TABLE A1.3. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-D MODULE 2 (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Written procedure/ instructions	**0**	**0**	**1.5**	**1.5**	**1**	**0.5**
- Welds			0.5	0.5	0.5	
- Castings			0.5	0.5	0.5	
- Corrosion wall thickness measurement			0.5	0.5		0.5
[c)]**Radiation protection** Extra training course depending on national regulations recommended	**1**	**1**	**1**	**1**	**1**	**0.4**
Total	**16.55**	**15.5**	**32.5**	**27.5**	**22.6**	**9.4**
	32		**60**		**32**	

[a)] In addition to the above 40 hours a general knowledge common core course for level 3 (applicable to all NDT methods) is recommended, which shall be successfully completed only once.

[b)] More hours are recommended for RT-CT related training.

[c)] National laws and regulations are to be considered for training on radiation safety and handling of radiation sources. Radiation safety may be trained in separated courses, or training hours should be considered to be additional to those of the syllabus requirements (see TECDOC-628/Rev.2).

TABLE A1.4. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-S

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
General knowledge NDT	**0**	**0**	**0**	**0**	**0**	**0**
- Origin of discontinuities					a)	
- Need for NDT					a)	
- NDT methods, principles, advantages, applications and limitations					a)	
- Materials and processes					a)	
Physical principles of X-ray technique	1	0.5	1	0	1	0
- Structure of the atom	0.1		0.1			
- Atomic model			0.1			
- Electromagnetic spectrum			0.1			
- Sources of radiation, their properties, X-rays, gamma rays	0.2		0.1			
- Neutrons					0.2	
- X-ray and gamma ray spectrum			0.1			
- Essential radiographic parameters (voltage, current, activity)	0.1		0.1		0.1	
- Filters			0.1		0.1	
- Focal spot			0.1		0.1	
- General mechanism of interactions (photoelectric effect, Compton effect, pair production)	0.2		0.2		0.2	
- HVL, TVL and attenuation law	0.1					
- Hardening of radiation, filtering, collimation	0.1	0.5				
- Scattered radiation and build-up factor						
- Fluorescence					0.1	
- Attenuation of neutrons and electrons					0.2	
Radiation contrast, noise	**1**	**0**	**1**	**1**	**1**	**0**
- Contrast and noise	0.5					
- Specific contrast			0.2		0.2	
- Scatter influence	0.25		0.1	0.25	0.2	
- Signal-to noise ratio			0.2	0.25	0.2	
- Contrast-to noise ratio			0.2	0.25	0.2	
- Basic spatial resolution			0.1	0.25	0.1	
- Pixel size	0.25					
- Normalized SNR_N			0.2		0.1	

TABLE A1.4. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-S (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
b) Geometrical projection conditions	**1.5**	**2**	**2**	**2**	**2**	**1**
- Geometrical and inherent unsharpness	0.25	0.5	0.25	0.5	0.4	0.5
- Geometrical magnification	0.25	0.5	0.25			
- Effect of magnification	0.5	0.5	0.5	1	0.4	
- Optimum magnification			0.25		0.4	0.5
- Difference between radiography and radioscopy			0.5		0.4	
- Law oft he squared distances	0.5	0.5	0.25	0.5	0.4	
Optimisation of image quality	**1**	**0**	**1**	**1**	**1**	**0**
- Compensation principles	0.5					
- Contrast vs. SNR			0.3	0.5	0.2	
- Basic spatial resolution			0.3	0.5	0.2	
- Local unsharpness vs. SNR					0.2	
- Scatter protection	0.5		0.2		0.2	
- Maximum/optimum X-ray voltage			0.2		0.2	
Image quality indicators, standards	**1**	**1**	**0**	**0**	**0**	**0**
- Wire type	0.25	0.25				
- Step hole type	0.25	0.25				
- Plate hole type	0.25	0.25				
- Duplex wire type	0.25	0.25				
- Measurement of basic spatial resolution						
- Converging line pairs						
- Line pair gauges (MTF)						
- Standards (see clause Table 2)						
Equipment and work – Radiation sources	**1**	**2**	**1**	**1**	**1.5**	**0**
- X-Ray sources						
o Standard sources						
o Special source	0.25	0.5	0.1	0.2		
o Generation of high voltage			0.3	0.2	0.4	
o Cooling			0.2		0.1	
o Handling	0.25	0.5				
o Parameters : kV, mA, spot size		0.5	0.1	0.25	0.1	
o Measurement of parameters					0.5	
- Gamma sources and containers						
o Handling and projector	0.25	0.5	0.1	0.25	0.1	
o Special design			0.1	0.1	0.1	
o Parameters: isotope, activity, source size	0.25		0.1		0.2	

TABLE A1.4. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-S (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Equipment and work – detectors : CR, imaging plates	**1**	**0**	**1**	**0**	**1**	**0**
- Phosphor imaging plates, introduction and design	0.5					
- Imaging plate and CR scanner	0.25		0.2		0.1	
- CR system and classification			0.2		0.1	
- Quality assurance (phantom)			0.2		0.2	
- Exposure conditions and diagrams			0.3		0.2	
- Handling	0.25		0.1		0.2	
- System selection					0.2	
Equipment and work – detectors : DDAs	**1.5**	**1**	**1**	**1**	**1**	**1**
- Digital Detector Arrays (DDA)- Introduction and design	0.5	0.25	0.5		0.25	
o Indirect converting						
o Direct converting						
o CCD, amorph, Si, CMOS						
- Detector calibration		0.25	0.25	0.25	0.25	0.25
- Quality assurance			0.25	0.25	0.1	0.25
- Exposure conditions	0.5	0.25		0.25		0.5
- Handling	0.5	0.25		0.25	0.1	
- System selection					0.3	
Equipment and work – detectors : LDAs	**0.5**	**0**	**0.5**	**0**	**0.5**	**0**
- Line Detector Arrays (LDAs)- Introduction and design	0.25		0.25		0.1	
- Application areas	0.25		0.25		0.1	
- Comparison to DDAs					0.1	
- Quality assurance					0.1	
- Exposure conditions						
- Handling						
- System selection					0.1	
Equipment and work – detectors : intensifiers, fluoroscope	**1**	**1**	**1**	**1**	**0.5**	**0.5**
- Introduction and design	0.4		0.25		0.1	
- Application areas	0.2	0.25	0.25	0.25	0.1	
- Quality assurance				0.25	0.1	
- Exposure conditions		0.5	0.25	0.25		0.5
- Handling	0.2	0.25		0.25		
- System selection					0.1	
- Comparison to DDAs	0.2		0.25		0.1	

TABLE A1.4. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-S (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Equipment and work – detectors : film digitization - Scanner design o Camera based o Line scanners o Laser scanners - Quality assurance (EPRI test film) - Handling, archiving - System selection - Classification	**0**	**0**	**0**	**0**	**0**	**0**
Data acquisition, detector calibration - A/D interface - Computer structure o Processor, memory, bus, disk o Load and save of digital images o Image formats - Image integration o On chip integration o In memory integration o Optimum gain and latitude settings o Accumulation vs. integration	**0**	**0**	**1** 0.25 0.25 0.5	**1** 1	**1** 0.3 0.2 0.5	**0**
Digital image processing	**2**	**2**	**5**	**4**	**3**	**3**
- Image structure, quantisation - (bits and bytes)	0.5		0.5		0.25	
- Basic operation (picture element-pixel, gray value)	0.75	1	0.5		0.25	
- Point operations (contrast, brightness, gamma correction, histogram, LUT)	0.75	1	0.5	0.5	0.5	0.5
- Matrix operations, filter (smoothing, improvement of SNR, high pass, gradient, edge enhancement, line extraction)			2	1	1.5	1.5
- Measurement tools (calibration, line profile, measurement of flaw length, areas, depth)			0.5	1.5		1
- Correction of raw data (linearisation, LUT correction, bad pixel interpolation)			1	1	0.5	

TABLE A1.4. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-S (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
Standards	**1**	**1**	**3**	**3**	**2**	**0**
- Guides	0.5				0.5	
- Qualification of sources		0.5	0.5	0.5	0.5	
- General qualification of detectors			0.5		0.5	
- User qualification of detectors	0.5	0.5	2	2.5	0.5	
- See Table 2						
Defectology, digital catalogues	**0.5**	**0.5**	**1**	**1**	**1.5**	**0**
- General welding (ISO 6520) and casting defects (ASTM casting catalogues)	0.25	0.25	0.5		0.5	
- Evaluation of welding: IIW catalogue ISO 5817	0.25		0.5	0.5	0.5	
- Evaluation of casting: ASTM catalogues		0.25		0.5	0.5	
- Corrosion						
Automated image interpretation	**0**	**0**	**1**	**1**	**0.5**	**0.5**
- Principles			0.5		0.5	
- Binarisation			0.25	0.5		0.25
- Measurement of dimensions			0.25	0.5		0.25
b) Special techniques, computed tomography	**0**	**0**	**1**	**1**	**0.5**	**0.5**
- Stereo radiography						
- Laminography			0.25			
o Computed tomography					0.25	
o Inspection geometry			0.5	1	0.25	0.5
o 2D vs. 3D						
o Reconstruction principles						
o Filtered backprojection						
o Applications						
o Requirements and limit of method						
- Special CT techniques			0.25			
Applications, standard practices and evaluation	**2**	**3**	**2.5**	**2**	**1.5**	**2**
- Welds (standard practices with different exposure geometries, interpretation of digital images, digital processing of images, evaluation of flaws, measurement of flaw dimensions, written instruction/procedure)	1	1.5	1	1	0.5	1

TABLE A1.4. BREAK DOWN OF TRAINING HOURS FOR ALL LEVELS OF RT-S (cont.)

Training syllabus	Level 1 hours		Level 2 hours		Level 3 hours	
	Lecture	Practice	Lecture	Practice	Lecture	Practice
- Castings (standard practices with different exposure geometries, interpretation of digital images, digital processing of images, evaluation of flaws, use of catalogues, measurement of flaw dimensions, written instruction/procedure)	1	1.5	1	1	0.5	1
- Corrosion wall thickness measurement (tangential RT, double wall RT, calibration of digital images, measurement of thickness, written instruction/procedure)						
- Others…			0.5		0.5	
Written procedure/ instructions	**0**	**0**	**1**	**1**	**1**	**1**
- Welds			0.5	0.5	0.5	0.5
- Castings			0.5	0.5	0.5	0.5
- Corrosion wall thickness measurement						
[c] **Radiation protection** Extra training course depending on national regulations recommended	**1**	**1**	**1**	**1**	**1**	**1**
Total	**17**	**15**	**26**	**22**	**21.5**	**10.5**
	32		**48**		**32**	

[a] In addition to the above 32 hours a general knowledge common core course for level 3 (applicable to all NDT methods) is recommended, which shall be successfully completed only once.

[b] More hours are recommended for RT-CT related training.

[c] National laws and regulations are to be considered for training on radiation safety and handling of radiation sources. Radiation safety may be trained in separated courses, or training hours should be considered to be additional to those of the syllabus requirements (see TECDOC-628/Rev.2).

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