

INDE 2007
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by U. Ewert

Codes and Standards in Digital Industrial Radiology

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Status and new Situation

- **2005: Computed Radiology standards were completed and published in USA and Europe!**
- The Digital Industrial Radiology (DIR) procedure is different from the film radiography procedure
- The optical impression of digital radiographic images is not different from film images in its structure (if not digitally processed, except brightness and contrast control)
- RT-trained personal can interpret digital images in analogy to film
- Digital images need a PC 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 processing but the results may differ from those ones of film interpretation
- Electronic reference catalogues may support correct image assessment

New Standards on Digital Industrial Radiology

EN 13068	Radioscopy
EN 14096, ISO 14096	Film Digitisation
EN 14784 CR	Part 1: Classification of Systems, Part 2: General principles
ASTM CR	Classification (E 2446), Long term stability (E2445), Guide (E 2007), Practice (E 2033)
ASME CR Code Case 2476	Radiography (CR) with Phosphor Imaging Plates
ASTM E 07	DDA under development
ASTM E 2422	First digital catalogue , light alloy casting

Film Replacement

Standards, Regulations

- Welding
- Casting

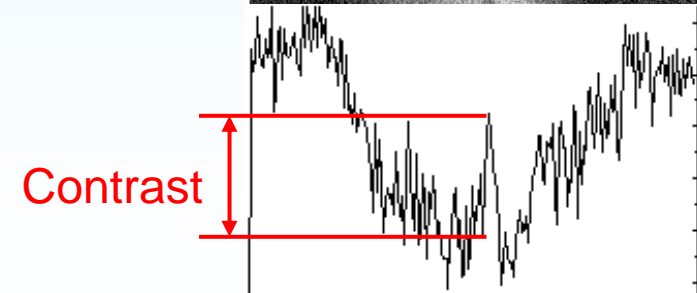
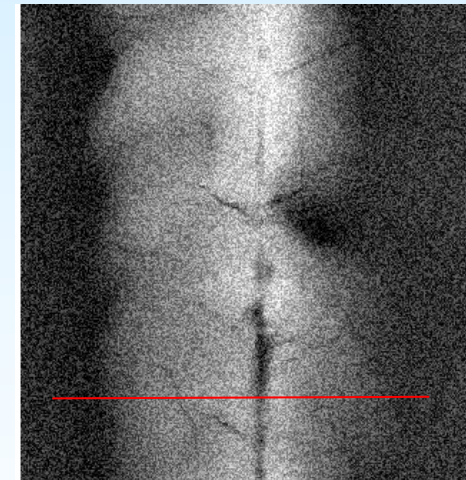
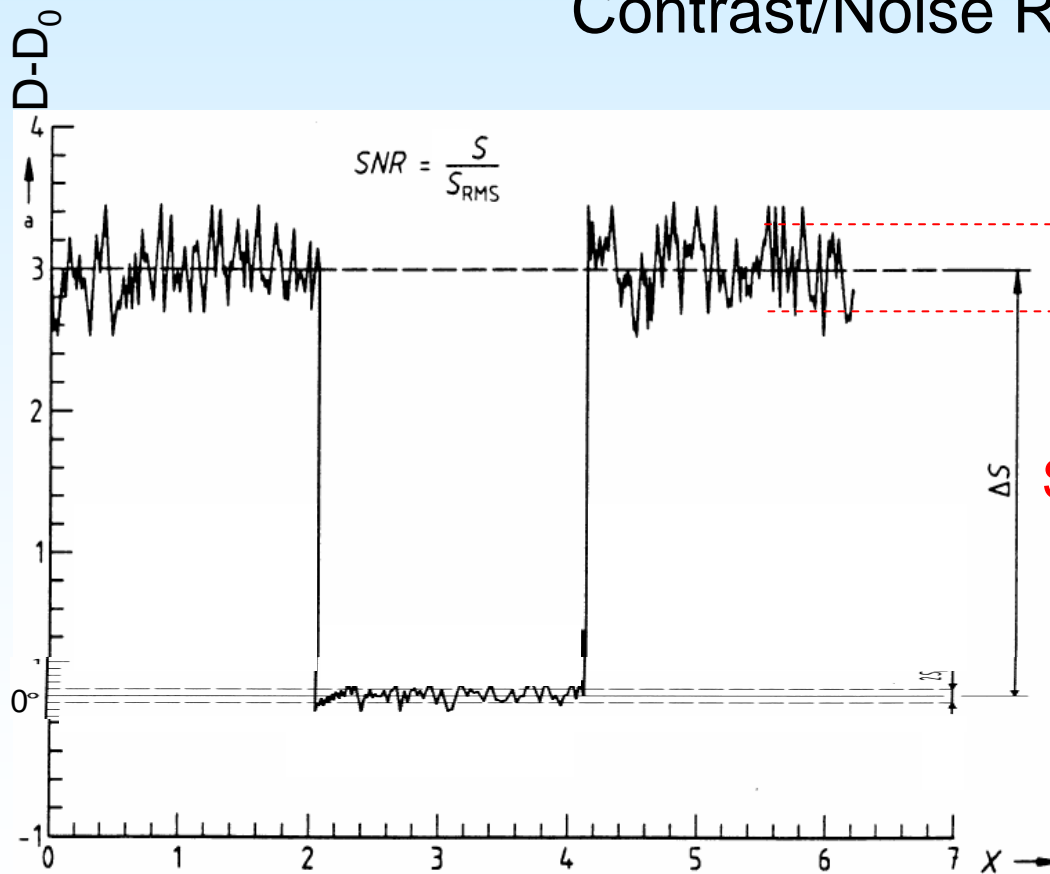
European CR Standards EN 14784 were developed to be comparable with Film Standards EN 444, EN 584-1, EN 462-5 !

All film based standards require:

- Minimum optical Density (e.g. > 2.0)
- Maximum film system class (e.g. \leq ASTM T2)
- Maximum unsharpness (> 0.1 mm, FFD/FOD)

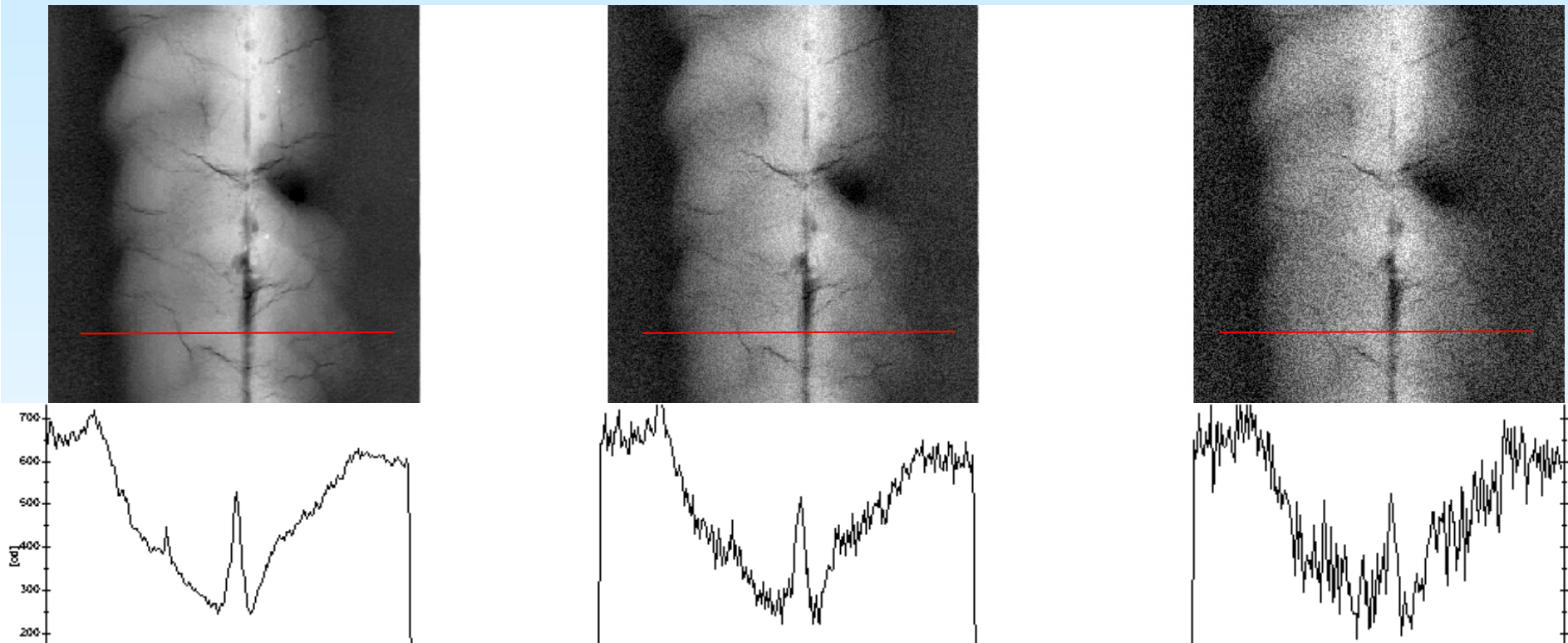
Signal/Noise Ratio as Equivalent to opt. Density

Definition of Signal/Noise Ratio and Contrast/Noise Ratio

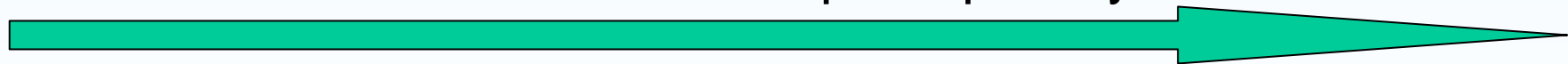


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Effect of Granularity or Noise

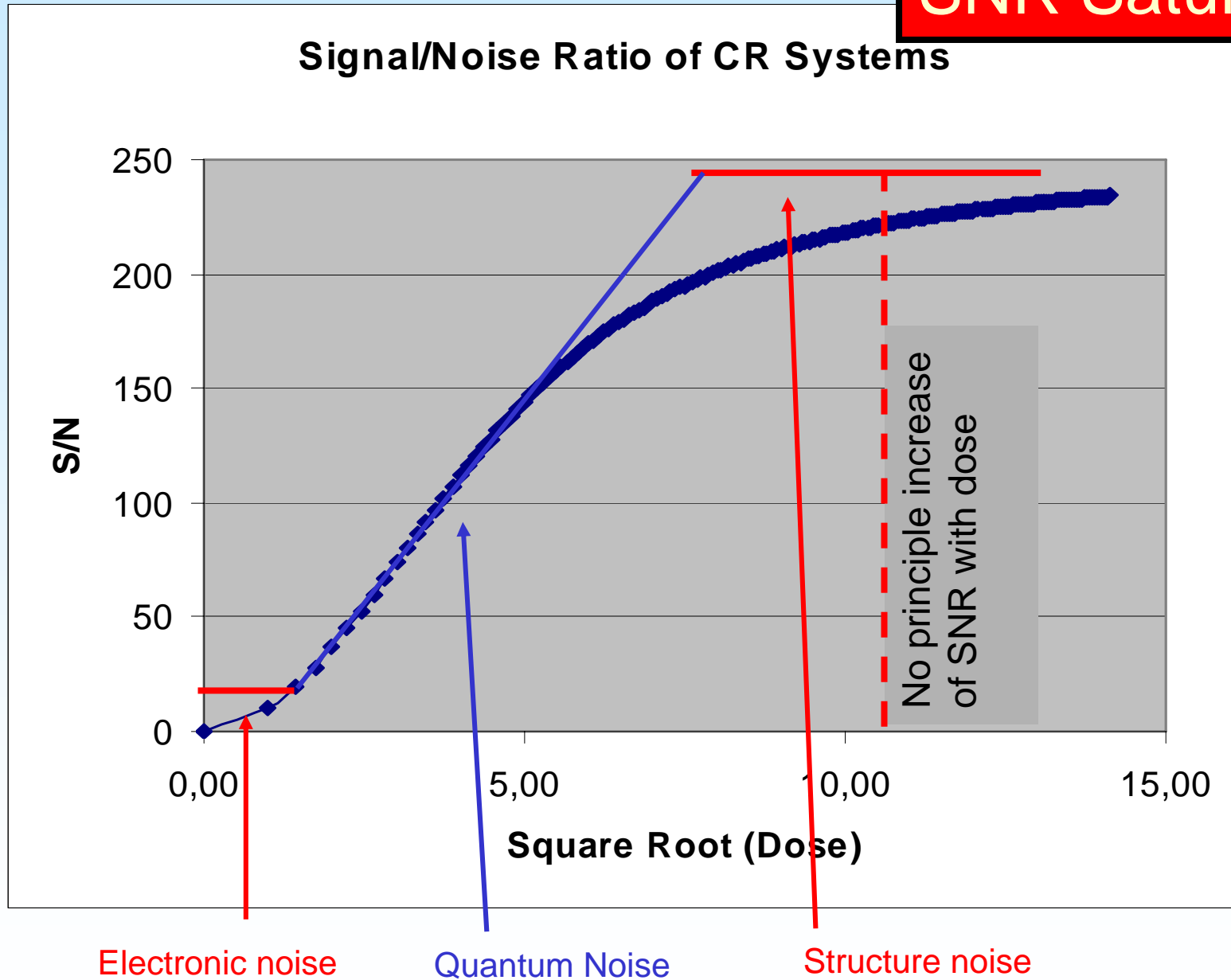


Lost of information / perceptibility



$$\sigma_D$$

SNR Saturation

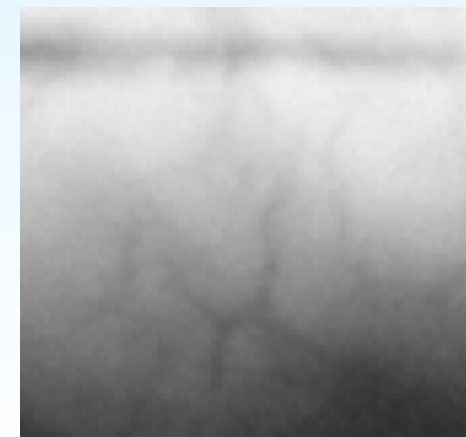
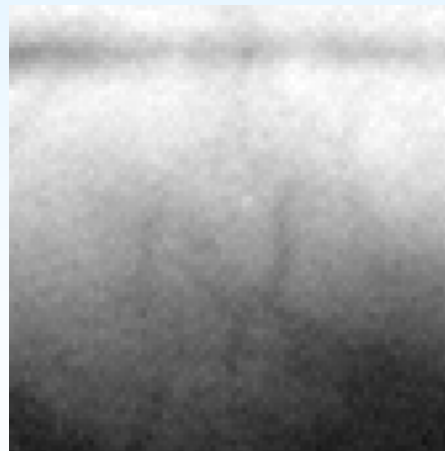
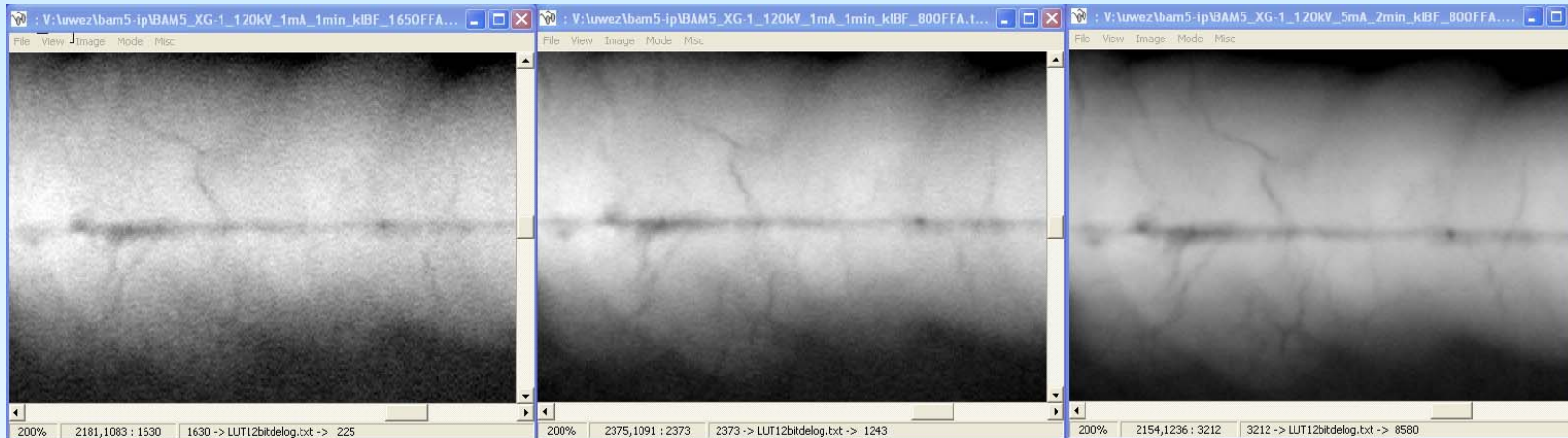


BAM 5 test weld, 8 mm Steel, 120 kV, different exposure time:

Exp. Time 1x

Exp. Time 4.3x

Exp. Time 43x

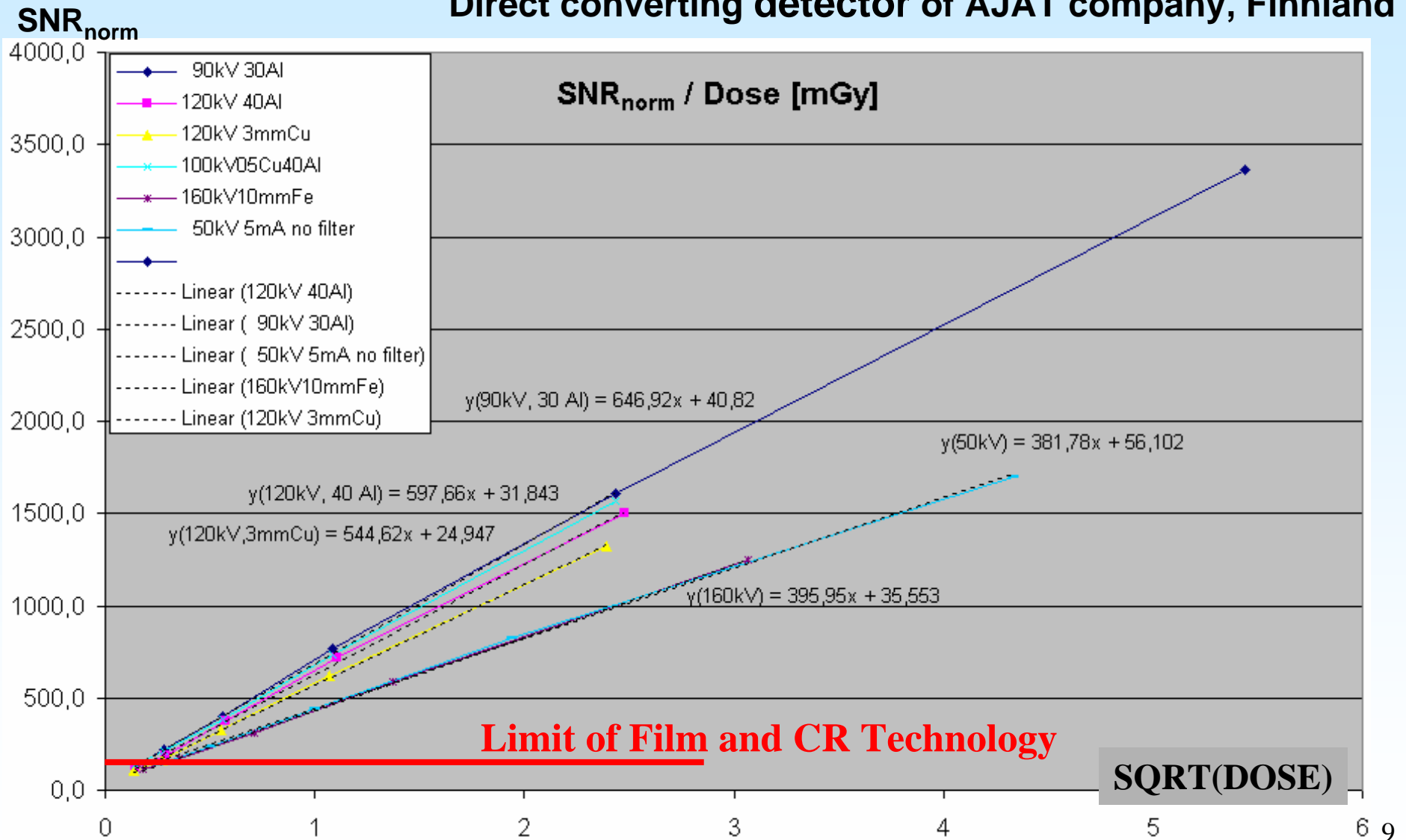


magnification

CR-System: FujiFilm DynamiX (XG 1) ⁸

Efficiency test “DDA Qualification Standard Proposal”, ASTM, USA

Direct converting detector of AJAT company, Finland





K. Bavendiek et al.

Fuji IX25

$\text{SNR}_{\text{norm}} \sim 265$

PerkinElmer 1620

$\text{SNR}_{\text{norm}} \sim 1500$

Bad Pixels of DDAs

- 6.2.1 *Dead Pixel*— Pixels which are completely dead, no response at all.
- 6.2.2 *Over responding pixel* — Pixels whose gray values are greater than 1.3 times the gray value of an area of a minimum of 21*21 pixels. This test is done on offset corrected image
- 6.2.3 *Under responding pixel* — Pixels whose gray values are less than 0.6 times the median gray value of an area of in a minimum of 21*21 pixels. This test is done on offset corrected image
- 6.2.4 *Noisy pixel* — Pixels whose standard deviation in a sequence of 30 to 100 images without radiation is more than 6 times the median pixel standard deviation for the complete DDA. This test is done on dark images.
- 6.2.5 *Non uniform pixel* — Pixel whose value exceeds a deviation of more than +/-1 % of the median value of its 9x9 neighbor pixel. The test should be performed with image Thus where the average gray value is at or above 75% of the DDAs linear range. This test is done on offset and gain corrected image.
- 6.2.6 *Persistence / Lag pixel* — Pixel whose value exceeds a deviation of more than +100 % of the median value of its 9x9 neighbors and >1% absolute in the first image after X-ray shut down.
- 6.2.7 *Bad neighborhood pixel*— Pixels, where all 8 neighbor pixels are underperforming pixels, as defined immediately above, are also considered underperforming pixels.

Proposal on “DDA Qualification Standard” ASTM, E07, USA

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Achievable Contrast Sensitivity and Exposure Time

- The contrast sensitivity improves with the increasing exposure time (becomes smaller!)
- The structural noise of the IPs limits the max. achievable SNR
- Step hole, plate hole and wire image quality indicators measure the increase of CNR and improvement of contrast sensitivity
- Unsharp digital detectors achieve a higher max. SNR and need less exposure time
- The normalized SNR_N is independent on the unsharpness, but depends on the efficiency and plate homogeneity
- Unsharp detectors for radiography with higher energy (about > 250 keV) yield a considerable reduction of exposure time in comparison to film.

CR System Selection

European Standard

EN 14784-2

Table 4 — Required spatial system resolution in dependence on energy and wall thickness

Radiation source	Wall thickness w in mm	Class IPA		Class IPB	
		Max. pixel ^a size μm	Double wire IQI number ^b	Max. pixel ^a size μm	Double wire IQI number ^b
X-ray $U_p \leq 50 \text{ kV}$	$w < 4$	40	$> 13^c$	30	$\gg 13^d$
	$4 \leq w$	60	13	40	$> 13^c$
X-ray $50 \text{ kV} < U_p \leq 150 \text{ kV}$	$w < 4$	60	13	30	$\gg 13^d$
	$4 \leq w < 12$	70	12	40	$> 13^c$
	$w \geq 12$	85	11	60	13
X-ray $150 \text{ kV} < U_p \leq 250 \text{ kV}$	$w < 4$	60	13	30	$\gg 13^d$
	$4 \leq w < 12$	70	12	40	$> 13^c$
	$w \geq 12$	85	11	60	13^c
X-ray $250 \text{ kV} < U_p \leq 350 \text{ kV}$	$12 \leq w < 50$	110	10	70	12
	$w \geq 50$	125	9	110	10
X-ray $350 \text{ kV} < U_p < 450 \text{ kV}$	$w < 50$	125	9	85	11
	$w \geq 50$	160	8	110	10
Yb 169, Tm 170		85	11	60	13
Se 75, Ir 192	$w < 40$	160	8	110	10
	$w \geq 40$	200	7	125	9
Co 60		250	6	200	7
X-ray $U_p > 1 \text{ MeV}$		250	6	200	7

^a If magnification technique is used, double wire IQI readout is required only.

^b The given IQI numbers indicate the readout value of the first unresolved wire pair corresponding to EN 462-5.

^c The symbol " > 13 " requires the 13th wire pair to be resolved with a dip separation larger than 20 % (see Figure 3 of EN 14784-1:2004).

^d The symbol " $\gg 13$ " requires the 13th wire pair to be resolved with a dip separation larger than 50 %.

U_p = tube voltage.

EN 14784-2

Proposed Typical Applications of CR

TABLE 1 Element Number, Corresponding Unsharpness and Wire Diameter^A

	Element Number	Corresponding Unsharpness (mm)	Wire Diameter and Spacing, <i>d</i> (mm)	Tolerance of Wire Diameter and Wire Spacing (mm)
Pt ^B	13	0.10	0.05	
Pt	12	0.13	0.063	
Pt	11	0.16	0.08	±0.005
Pt	10	0.20	0.10	
Pt	9	0.26	0.13	
Pt	8	0.32	0.16	
Pt	7	0.40	0.20	
Pt	6	0.50	0.25	±0.01
Pt	5	0.64	0.32	
Pt	4	0.80	0.40	
W ^C	3	1.00	0.50	
W	2	1.26	0.63	±0.02
W	1	1.60	0.80	

^A This table is based on data provided in EN 462-5.

^B Pt = Platinum.

^C W = Tungsten.

**New Discussion of
European Project FilmFree
for standard revision!**

Contact shot with no geometric enlargement

Aerospace components

**Nuclear weldments
Thin pipe welds: $w > 4$ mm**

**Pipe weld medium & thick
wall $w > 12$ mm**

**Casting inspection
 $w > 50$ mm, γ -radiography**

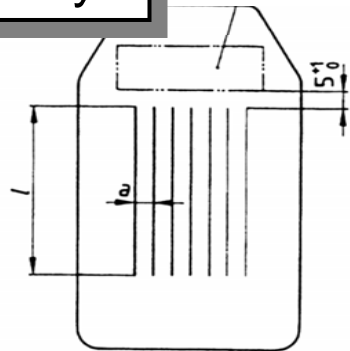
Required Image Quality Indicators

See also ASTM E747-97
→ but different to EN 462

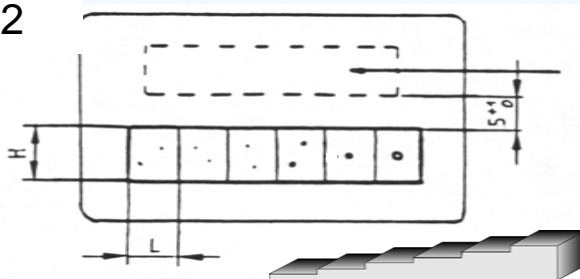
Description of Wire -IQI

For contrast only !

Wire IQI
EN 462-1

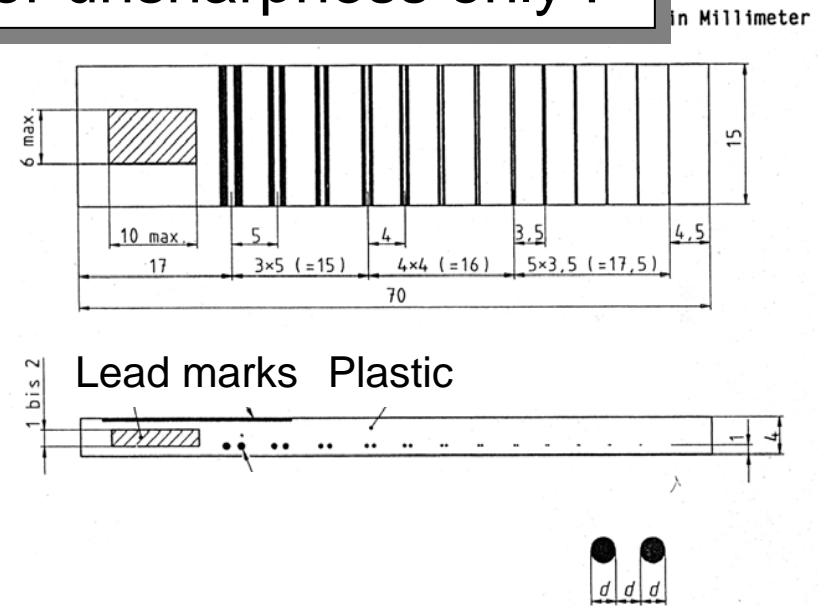


Step-Hole IQI
EN 462-2



Both IQI's are required
for CR!

For unsharpness only !



Duplex wire IQI / EN 462-5 / ASTM
E 2002

Digital Radiology for Weld Inspection in Europe

**Quality Levels for Welding are defined
in:**

EN ISO 5817 and EN ISO 10042

- Basis for Manufacturer and User
Contracts
- Harmonized with European Pressurised
Equipment Directive!

Quality Levels by EN ISO 5817

Title: “Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections”

- ISO 5817 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 10, *Unification of requirements in the field of metal welding*.
- The standard is considered as harmonized with the European Pressurized Equipment Directive (PED) and EN 13445

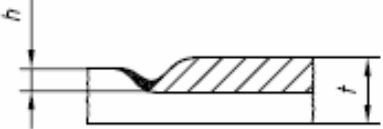
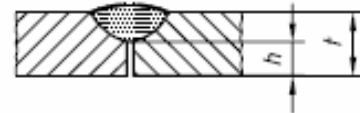
Quality Levels by EN ISO 10042

Title: “Welding — Arc-welded joints in aluminum and its alloys — Quality levels for imperfections”

What is EN ISO 5817 ?

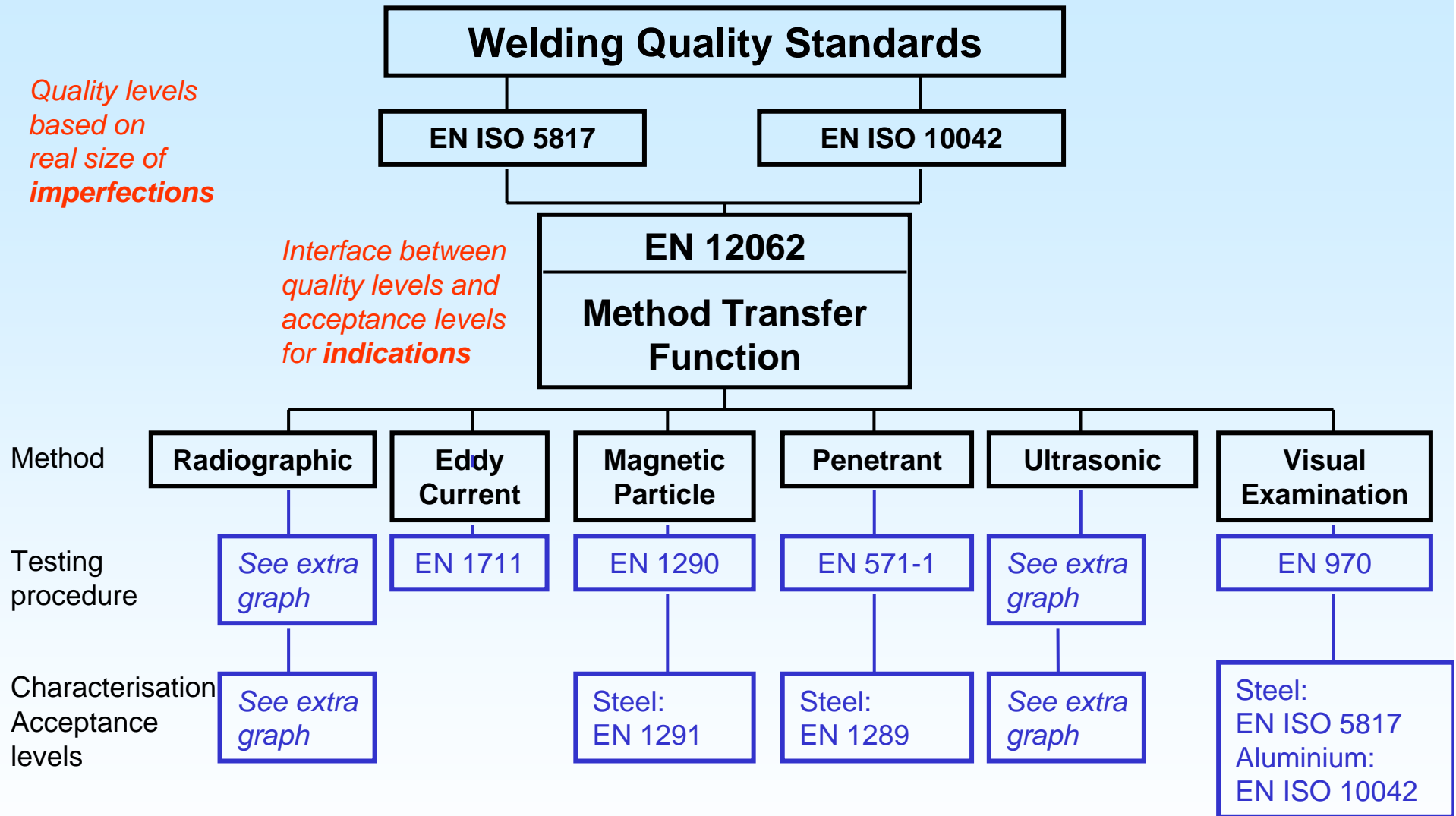
Example page

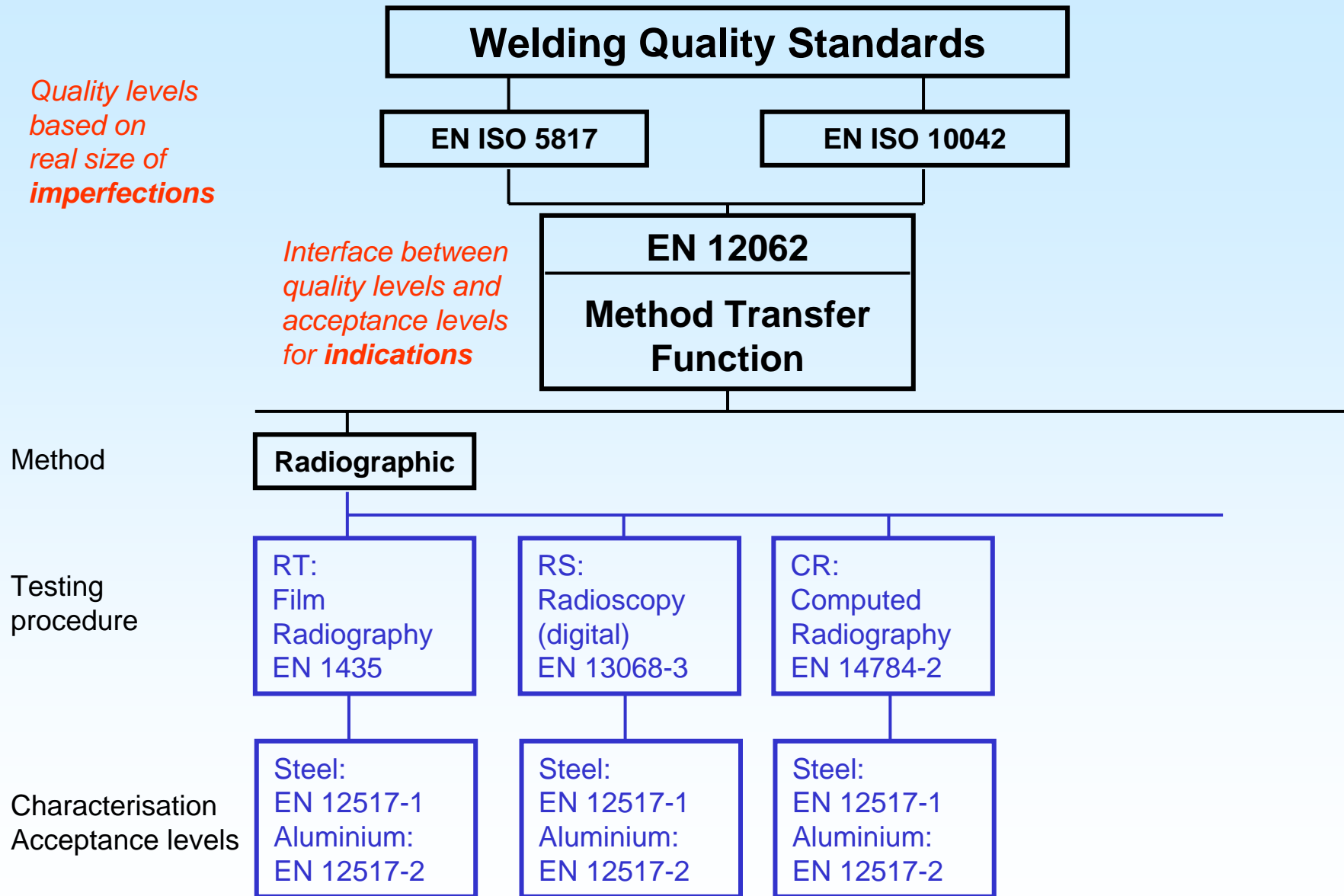
Table 1 — Limits for imperfections

No.	ISO 6520-1 reference	Imperfection designation	Remarks	r mm	Limits for imperfections for quality levels		
					D	C	B
1 Surface imperfections							
1.1	100	Crack	—	$\geq 0,5$	Not permitted	Not permitted	Not permitted
1.2	104	Crater crack	—	$\geq 0,5$	Not permitted	Not permitted	Not permitted
1.3	2017	Surface pore	Maximum dimension of a single pore for — butt welds — fillet welds	0,5 to 3	$d \leq 0,3 s$ $d \leq 0,3 a$	Not permitted	Not permitted
			Maximum dimension of a single pore for — butt welds — fillet welds	> 3	$d \leq 0,3 s$, but max. 3 mm $d \leq 0,3 a$, but max. 3 mm	$d \leq 0,2 s$, but max. 2 mm $d \leq 0,2 a$, but max. 2 mm	Not permitted
1.4	2025	End crater pipe		0,5 to 3	$h \leq 0,2 t$	Not permitted	Not permitted
				> 3	$h \leq 0,2 t$, but max. 2 mm	$h \leq 0,1 t$, but max. 1 mm	Not permitted
1.5	401	Lack of fusion (incomplete fusion)	—	$\geq 0,5$	Not permitted	Not permitted	Not permitted
		Micro lack of fusion	Only detectable by micro examination		Permitted	Permitted	Not permitted
1.6	4021	Incomplete root penetration	Only for single side butt welds 	$\geq 0,5$	Short imperfections: $h \leq 0,2 t$, but max. 2 mm	Not permitted	Not permitted

Materials and type of joint	Thickness in mm 1)		
	$t \leq 8$	$8 < t \leq 40$	$t > 40$
EN 12062 Selection of Methods			
Ferritic butt-joints	RT or (UT)	RT or UT	UT or (RT)
Ferritic T-joints	(UT) or (RT)	UT or (RT)	UT or (RT)
Austenitic butt-joints	RT	RT or (UT)	RT or (UT)
Austenitic T-joints	(UT) or (RT)	(UT) and/or (RT)	(UT) or (RT)
Aluminium butt-joints	RT	RT or UT	RT or UT
Aluminium T-joints	(UT) or (RT)	UT or (RT)	UT or (RT)
Nickel-and copper-alloys butt joints	RT	RT or (UT)	RT or (UT)
Nickel-and copper-alloys T-joints	(UT) or (RT)	(UT) or (RT)	(UT) or (RT)
Titanium butt-joints	RT	RT or (UT)	
Titanium T-joints	(UT) or (RT)	UT or (RT)	

() indicates that the method is applicable with limitations.
1) Thickness, t , is the nominal thickness of the parent material to be welded.





Radiography Replacement by TOFD

CEN TC 121 WG 2: **TOFD Acceptance Levels**

- A new standard project under 5 month inquiry at CEN
- Making TOFD an acceptable NDT technique to test and evaluate welding quality in lieu to radiography
- With critical disagreements to ISO 5817

ToFD – Time of Flight Diffraction is a 2 probe Ultrasound Technique

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Principle Set Up for ToFD

ASTM E 2373-04

TOFD Configuration and Signal origins

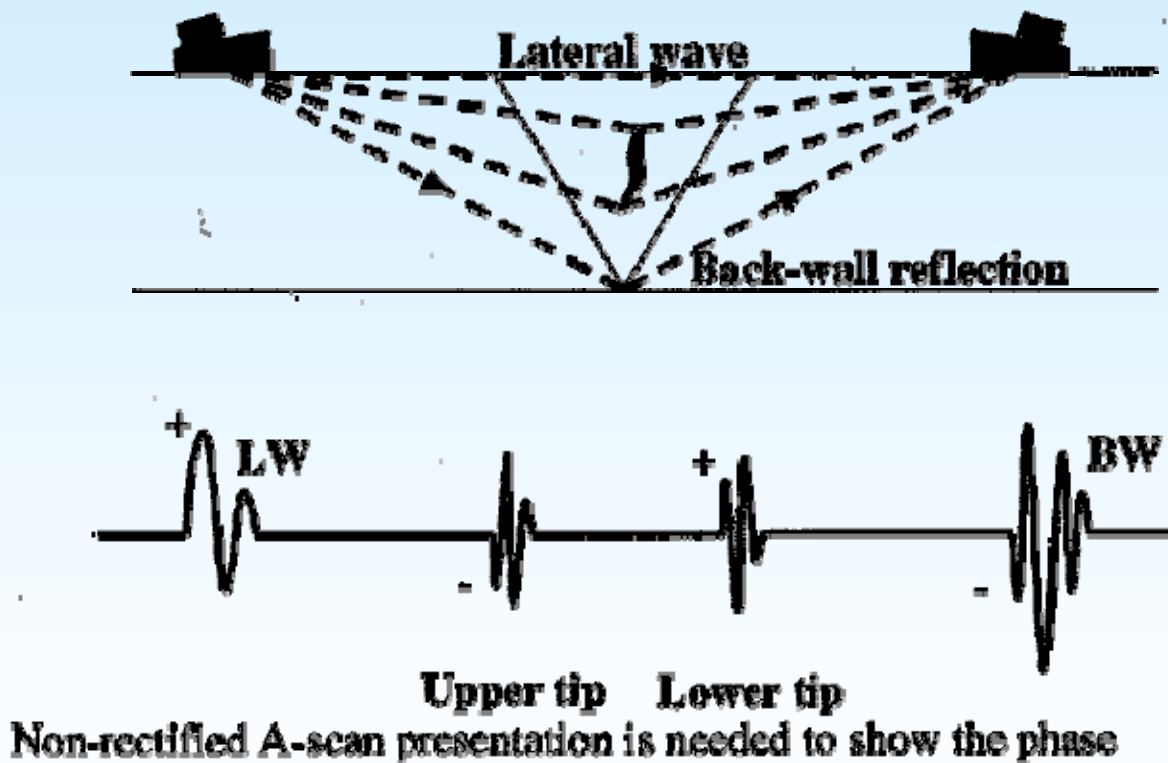
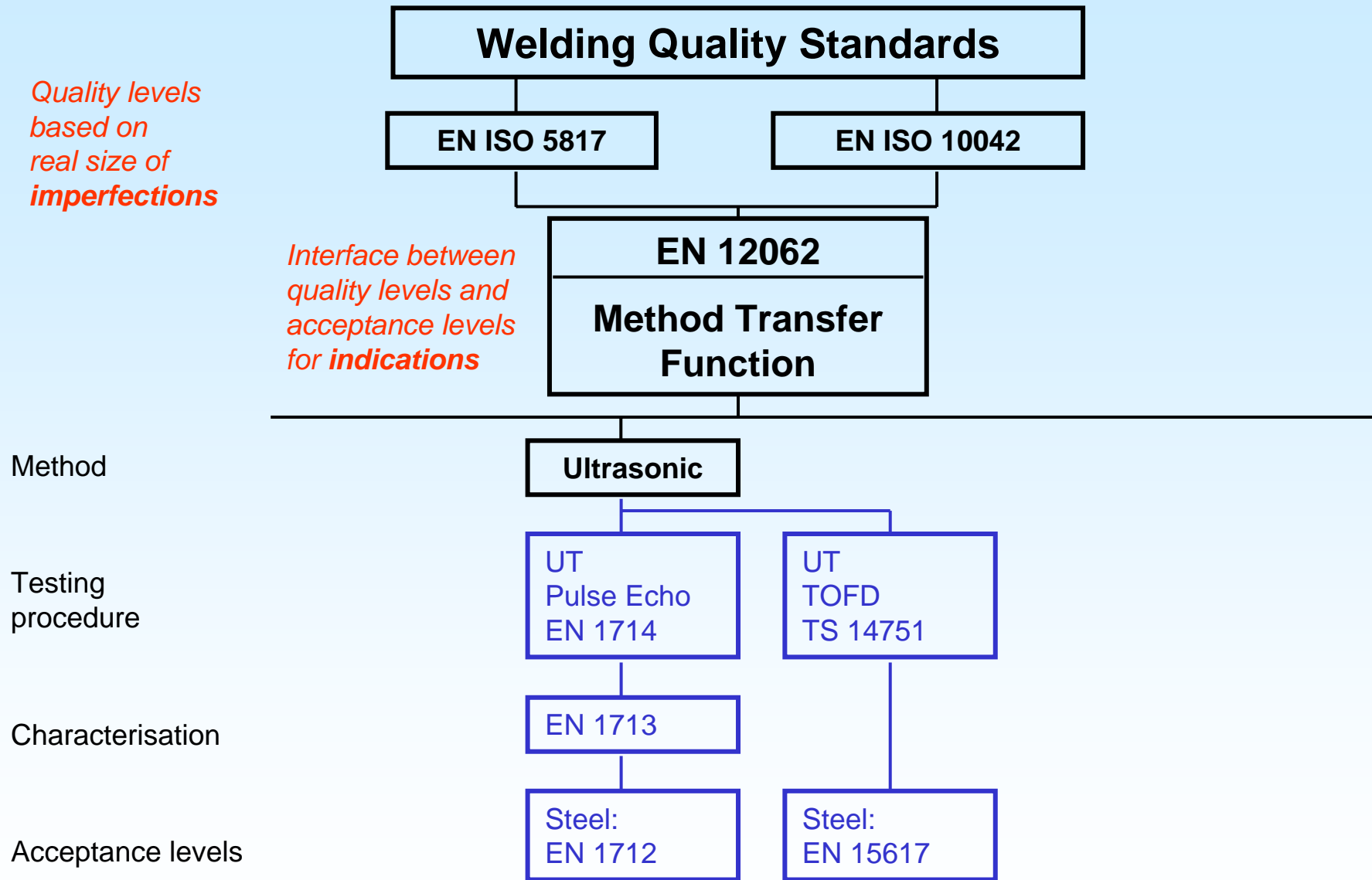


FIG. 1



IIW Conclusions in Paris 2001 and Florence 2000:

Automated UT and ToFD – Techniques versus Radiography
- a contradictory discussion -

ToFD:

The ToFD problem in the surface-near regime was especially discussed, where the defect echo is hidden by the direct surface echo and where as pulse echo clearly can detect the defect. One reasonable approach can be the combination of pulse echo and ToFD or the combination of ToFD and other surface methods like PT/MT.

Radiography:

The classical radiography approach mainly is limited by the capabilities of the human beings as inspectors but also by the limited range of available incident angles to optimal crack detection in a standard radiographic procedure. Therefore, one needs approaches like Tomographic Methods in order to overcome these limits. These methods today are on the way to become available.

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Film Replacement

the Procedure

Film System Classes are the Basis for all Classifications of Digital Detectors

Tab. 1: Overview about the film system classes in different standards and the corresponding SNR values and G_2/σ_D values.

$$\text{SNR} = \log(e) \cdot (G_2/\sigma_D) \text{ for linear detectors only}$$

System class				Minimum gradient-noise ratio at	Signal to Noise Ratio
World ISO 11699-1	Europe CEN 584-1	USA ASTM E1815-01	Japan K7627-97	D=2 above D_0	D=2 above D_0
				G_2/σ_D	SNR
T1	C1	Special I	T1	300	130
	C2			270	117
T2	C3	II	T2	180	78
	C4			150	65
T3	C5	III	T3	120	52
T4	C6		T4	100	43
		W-A	W-A	135	
		W-B	W-B	110	
		W-C	W-C	80	

What is Optical Density 2 at a Digital Detector?

This was our first question after getting a new system!

- Lets give an answer and develop a standard -

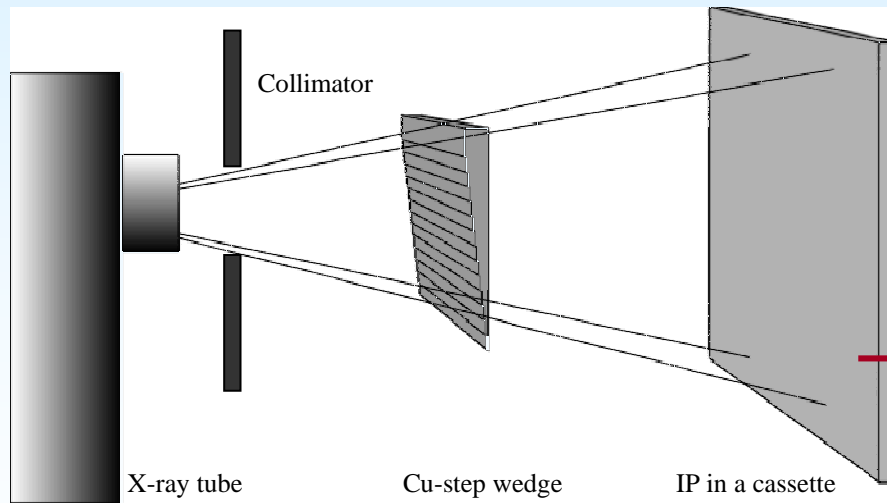


Fig. 1: Scheme for the measurement of the SNR with the step wedge method.

CR

Grey value 956
Sensitivity 400
Latitude 3
SNR > 130

Film



Opt. Density = 2

Do all values above 956 fulfill the standard requirement?

What is Optical Density 2 at a Digital Detector?

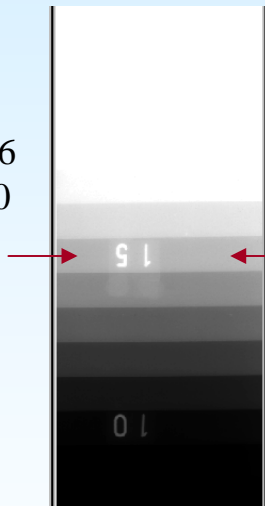
Characterization by (prEN 14784-1)
 - SNR and Spatial resolution
 e.g.: IP-3/200



CR

Film

Grey value 956
 Sensitivity 400
 Latitude 3



Opt. Density = 2

Do all values above 956 fulfil the standard requirement?

Answer: Yes they do! More than this!
 One CR system substitutes different film systems

Grey value (read-out value)	Film system class
956	Special
815	T1 (D4)
712	T2 (D7)
608	T3

New Development of Standard Conform Software for CR and Other Digital Technologies

Software IC:
(I see)

<http://www.kb.bam.de/~alex/ic.htm>



Normalized SNR

Considers:

- Image processing
- Basic spatial resolution (EN 14784)
- Normalized SNR (EN 14784)
- Wall thickness measurement
- Synchronized image viewing of reference radiographs



Digital Reference Images

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