

## **EVALUATING PERFORMANCE CHARACTERISTICS OF X-RAY EQUIPMENT AND FILM SYSTEMS WITHOUT THE USE OF ELECTRONIC MEASUREMENT AND/OR SPECIAL INSTRUMENTS**

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**Abstract:** Measurement and control of characteristics of NDT equipment and system that produce output to be interpreted by inspector is one of the most important tools for NDT reliability. Control activity should be based on:

- initial accurate measurement and calibration,
- periodical check to assure maintenance of calibration status,
- immediate verification and corrective action when any malfunctioning is suspected.

"Self-calibration" intended as capability of NDT facility to calibrate and control its own equipment and systems is very important for continuous and reliable activity. Typical approach based on this philosophy is ASTM E317 "Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Examination Instruments and Systems Without the Use of Electronic Measurement Instruments" that is applicable to shop or field conditions.

Is "Self-calibration" applicable to radiographic system too? Many characteristics can be self-determined according to existing practices and methods, but other ones require assistance and cooperation of supplier both for film system and x-ray equipment.

A certified film system being controlled by pre-exposed film strips can be adopted as "measurement device" for X-ray output concerning both intensity and contrast.

Basically x-ray equipment manufacturer performs initial accurate measurement and calibration using electronic measurement and/or special instrumentation as necessary. Then specific film set on "low-price" blocks and specimens is produced according to standard practice whose guidelines are supplied by this paper. Film set, blocks, specimens and results referred to specific film system will be the reference kit for periodical check in NDT facility.

This paper supplies some guidelines for standard practice based on testing using mainly GE Inspection Technologies radiographic system being available in Avio facilities.

**Introduction:** Following "Self-calibration" subjects are discussed in this paper:

1. X-ray equipment check based on films independent from processing fluctuation
2. Duty Cycle characterization
3. KV comparison among different X-ray machines
4. Focal spot measurement
5. Concept of equivalent radiograph
6. Introduction of alternate film of other manufacturer in a Certified Film System

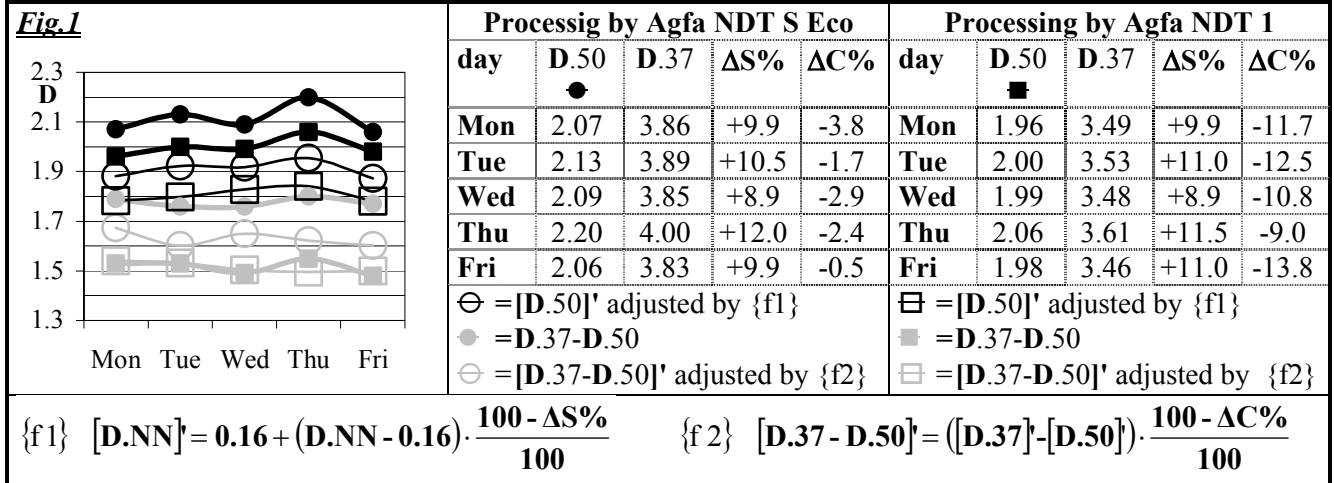
**Results:** This paper shows that "Self-calibration" is possible concerning aspects affecting quality image as film processing monitoring, Duty Cycle, kV, focal spot, film processed by chemistry of other manufacturer. Additional electronic measurement instrumentation is not requested to NDT facility except standard densitometer and light-meter for viewer check. Equipment outside forwarding may be generally avoided saving money and time. Determinations and parameters may be used for selection of radiographic equipment and system also. Similarly to Ultrasonic Testing, issue of "Standard Practice for Evaluating Performance Characteristics of Radiographic Equipment and Systems Without the Use of Special Measurement Instruments" establishing standard testing condition could be very useful.

**Discussion:** Preliminary it is to be note that for an effective "Self-calibration" status, performances should be evaluated by parameters that are directly measurable by radiologist in shop or field conditions without use of instrumentation in addition to that normally available in a good radiographic facility: e.g. variation of film density and contrast measured by densitometer shall be preferred to mA and kV accuracy measured by electronic measurement instruments generally reported in equipment brochure. In following subjects directly measurable parameters are identified.

### 1. X-ray equipment check based on films independent from processing fluctuation

Parameters: film density (**D**), Speed and Contrast Index discrepancy according to EN 584-2 ( $\Delta S\%$  and  $\Delta C\%$ ).

Normally daily X-ray equipment is checked by standard exposure using pre-determined parameters considering as acceptable **D** variation within  $\pm 15\%$ . Example in **Fig.1** concerns a week where X-ray equipment Isovolt 160HS is daily checked (150 kV, FE.50 and .37 blocks, Agfa D4, processors Agfa NDT S Eco and NDT1).

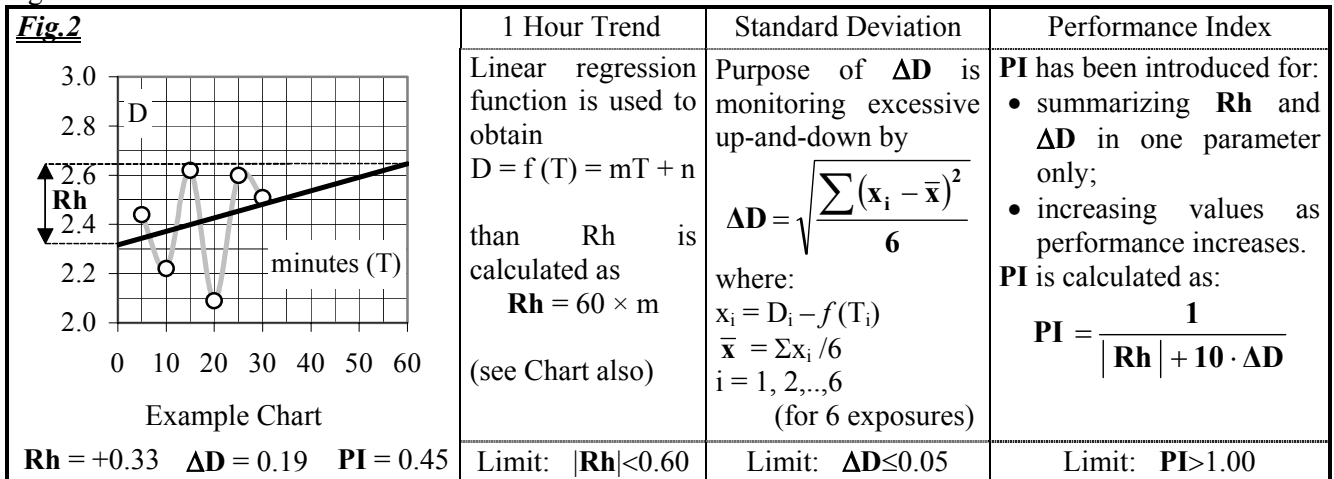


Introducing adjustment by  $\{f1\}$  and  $\{f2\}$  based on pre-exposed film strips Agfa PMC processed together films on the blocks,  $\ominus/\boxminus$  and  $\ominus/\boxminus$  are more independent than  $\bullet/\blacksquare$  and  $\bullet/\blacksquare$  from processing fluctuation and are more convenient to correlate X-ray equipment performances in different conditions and dates.

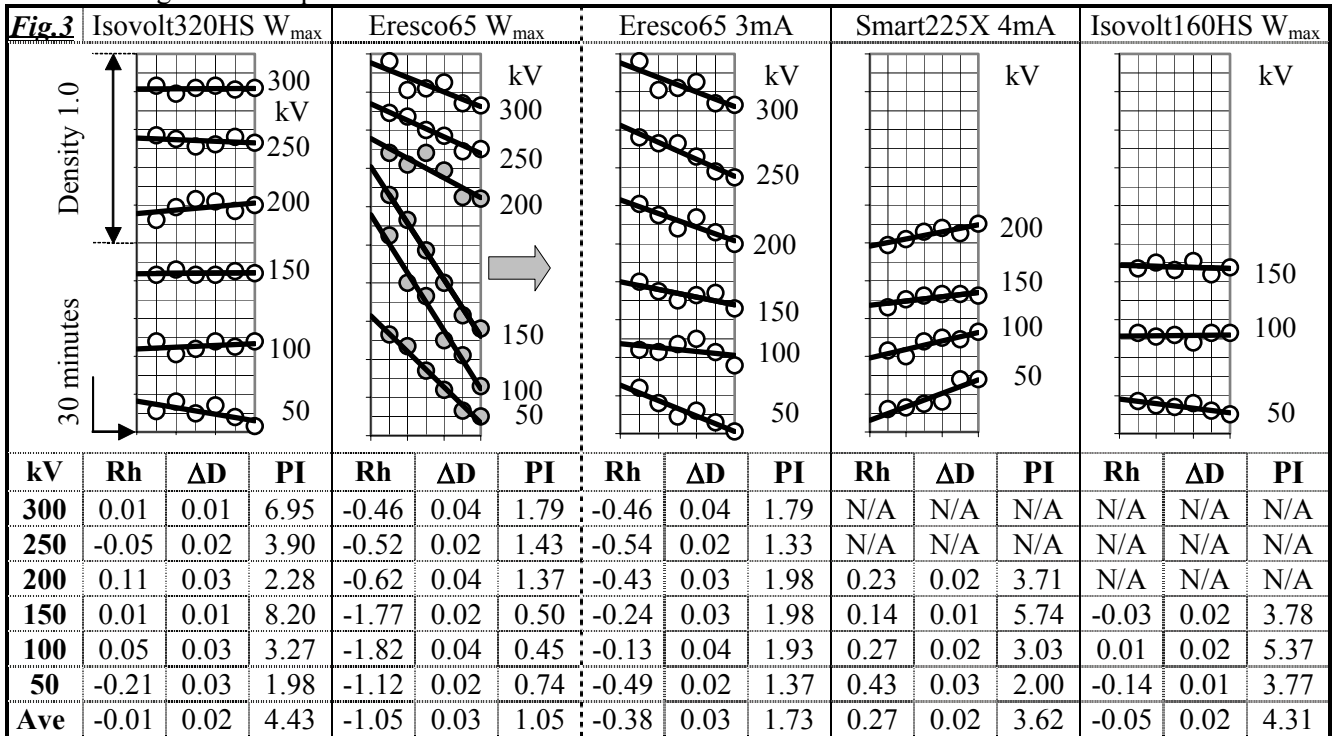
### 2. Duty Cycle characterization

Parameters: 1 Hour Trend (**Rh**), Standard Deviation ( $\Delta D$ ) and Performance Index (**PI**) as defined in **Fig.2**.

Some times brochure declares very optimistic Duty Cycle: for radiologist useful Duty Cycle shall allow continuously same density when thermal security switches off. So testing concerning actual performances in the whole operational range should be carried out. Six exposures 4'ON/1'OFF (Duty Cycle 80%) are carried out on standard blocks for penetrameters to obtain 6 films to measure density variation in 30 minutes using as mA as possible for stable emission; focal to film distance from 50 to 200 cm to obtain initially density in the range from 2.5 to 3.5; Agfa D4 with lead screens 0.027 mm over 120 kV has been used.



**Fig.3** shows results concerning 4 X-ray machines being available in Avio facility in Rivalta. Values exceeding limits are highlighted by gray background. Last line supplies average values intended for general comparison.



Eresco 65MF2 shows unstable X-ray output until 200 kV where maximum Wattage is used (e.g. 900W=6mAx150kV). So operational limit of 3 mA is introduced for further testing.

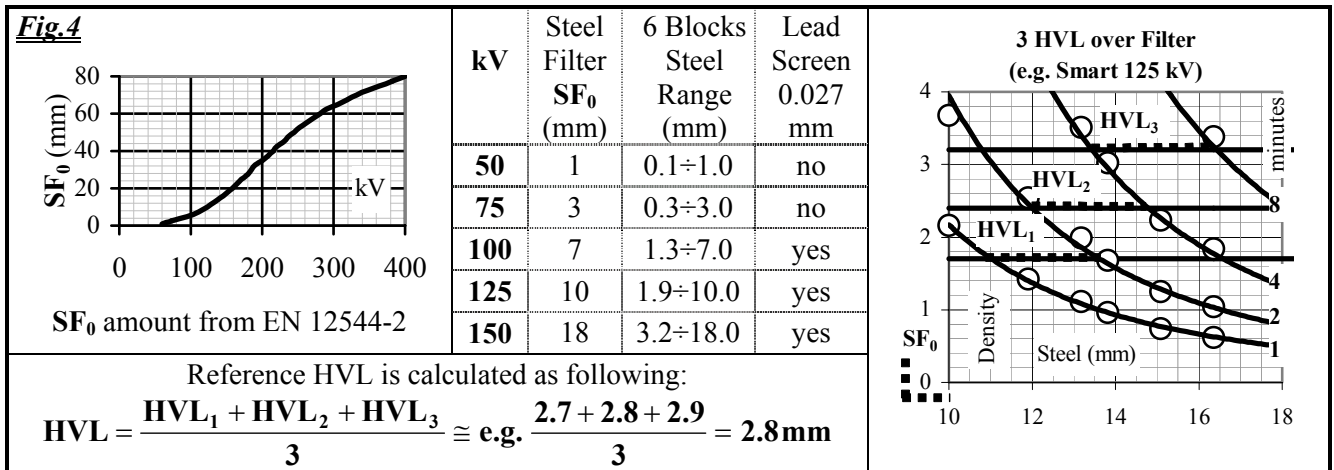
### 3. KV comparison among different X-ray machines

**Parameters:** Steel Half Value Layer (HVL) that reduces X-ray intensity to 50% as defined in

#### Fig.4.

KV calibration knowledge is very important to obtain equivalent radiographs in terms of contrast using different equipment. So testing to compare different X-ray machines have been carried out in range from 50 to 150 kV. Steel filter is placed on X-ray window in order to cut low energy spectrum. Six steel blocks at least are placed on film Agfa D7 to determine HVL besides filter. No intensifying lead screen is used under 100 kV.

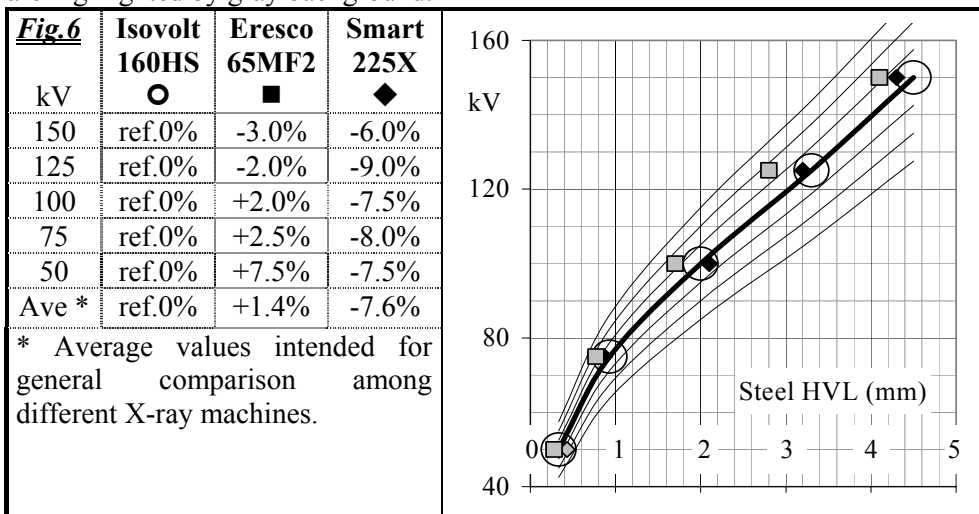
First short exposure (from 30 to 60 seconds) shall performed at Source to Film Distance of 50 cm. mA shall be maintained in stability range as determined in para.2. SFD and/or mA can be adjusted in order to obtain film density from 1.0 to 2.5 where filter only is crossed through. Then further 3 exposures are performed each one using double time referred to the previous one (e.g. 2, 4 and 8 minutes where first exposure is 1 minute). Density shall be measured as close as possible to X-ray beam axis (beam within angle  $\pm 6^\circ$  is used only). 3 HVL shall be determined so that increment doesn't exceed  $\pm 15\%$  (see Fig.4). Where increment between consecutive HVLs exceeds  $\pm 15\%$ , exposures shall be repeated after increasing filter thickness.



**Fig.5** shows results concerning 3 X-ray machines: Isovolt 320HS was not available at the moment of the test.

<b>Fig.5</b>	50 kV HVL	75 kV HVL	100 kV HVL	125 kV HVL	150 kV HVL
<b>Isovolt 160HS</b>	0.33 mm steel	0.93 mm steel	2.0 mm steel	3.3 mm steel	4.5 mm steel
<b>Eresco 65MF2</b>	0.43 mm steel	0.87 mm steel	2.1 mm steel	3.2 mm steel	4.3 mm steel
<b>Smart 225X</b>	0.28 mm steel	0.77 mm steel	1.7 mm steel	2.8 mm steel	4.1 mm steel

New Seifert Isovolt HS is selected as reference equipment due to standard provided with special electronic device for measurement and evaluation of X-ray tube voltage by divider method according to EN 12544-1 allowing periodic control. HVLs exceeding  $\pm 10\%$  from Isovolt 160HS are highlighted by gray background.



Plotting kV versus HVL from **Fig.5**, **Fig.6** is obtained that allows kV correlation among Smart 225X, Eresco 65MF2 and Isovolt 160HS: e.g. 150kV for Isovolt 160HS is equivalent to 150(-6%)=159 kV for Smart 225X. Curves in the chart represent steps of 5% kV. kV variations over  $\pm 3\%$  are highlighted by gray background.

What about limit of kV discrepancy? Following requirements have been found: ASTM E2104 para.7.12 establishes that no resubmittal for approval is requested for X-ray technique where kV change is within  $\pm 15\%$  or within  $\pm 5\%$  with mAs within 10%; EN 12544-1 page 5 establishes 1% of max kV in case of highly stabilized constant potential for sophisticated applications (e.g. tomography or dosimetry) and 3% for general applications. For equivalent radiographs purpose kV variation could be taken into account where over  $\pm 3\%$  against reference equipment that shall be certified by manufacturer according to EN 12544-1 or equivalent.

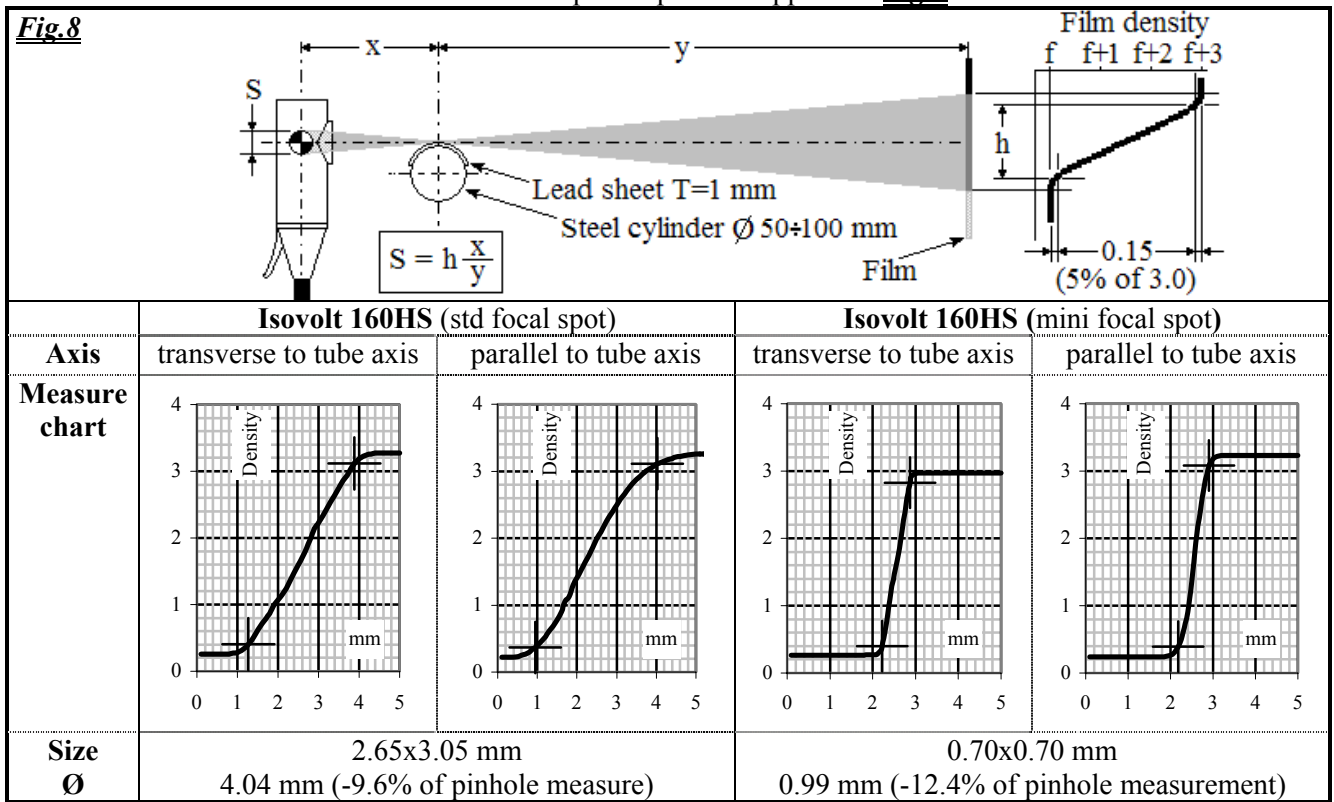
#### 4. Focal spot measurement

Parameters: Diagonal of spocal spot (Ø).

Normally pinhole camera method is used according to ASTM E1165. **Fig.7** shows some determinations carried on by Avio RT Lab. To be noted that, as requested by ASTM E1165 para. 7.1, actual size parallel to tube axis is determined multiplying the measured size in the picture by a correction factor of 0.7.

<b>Fig.7</b>	<b>Isovolt 160HS (std focal spot)</b>	<b>Isovolt 160HS (mini focal spot)</b>	<b>Eresco 65MF2</b>	<b>Smart 225X</b>	<b>Old damaged focal spot</b>
<b>Focal spot shape</b>					
<b>Size Ø</b>	3.20x3.12 mm 4.47 mm	0.83x0.76 mm 1.13 mm	1.80x1.61 mm 2.41 mm	1.95x1.78 mm 2.64 mm	1.85x1.44 mm 2.34 mm

Pinhole camera device requiring 3 platinum-gold diaphragms is more expensive than edge method according to EN 12543-4 that requires a steel cylinder only. **Fig.8** shows method and results obtained on Isovolt 160HS whose focal spot shapes are supplied in **Fig.7**.



Discrepancy between pinhole and edge method can be disregarded taking into account that ASTM E1165 para. 9.1.2 attributes to this method a measurement tolerance of  $\pm 30\%$  for nominal focal spot size from 0.3 to 1.2 mm,  $\pm 25\%$  from  $>1.2$  to 2.5 mm and  $\pm 20\%$  from  $>2.5$  mm. The only advantage of pinhole method against edge method is information about focal spot status: e.g. the old damaged focal spot shown in **Fig.7** finished to work after few weeks from determination detecting craters (2 white spots in the picture).

### 5. Concept of equivalent radiograph

**Parameters:** reliable Duty Cycle (**DC**) and minimum Exposure Time (**ExpT**) producing same Contrast (**Co**) and same Geometrical Unsharpness (**Ug**) by different X-ray machines.

Now we are able to self-establish reliable Duty Cycle per para.2, to self-evaluate kV discrepancy per para.3 and to self-measure focal spot size per para.4, so we are ready to speak about equivalent radiograph using an example concerning radiograph of two steel blocks .50 and .37 by Agfa D4 at about 150 kV.

**Fig.9** explains concept of equivalent radiograph and allows some comparison among different X-ray machines.

<b>Fig.9</b>	<b>Isovolt 160HS</b> (std focal spot)	<b>Isovolt 160HS</b> (mini focal spot)	<b>Eresco 65MF2</b>	<b>Smart 225X</b>
<b>Ø</b> (see para.4) ↓	4.47 mm	1.13 mm	2.41 mm	2.64 mm
<b>Reliable DC</b> (see para.2) ↓	No limitations (20 mA max)	No limitations (4 mA max)	3 mA max	No limitations (4.0 mA max)
<b>Preliminary exposure</b> for density 2.16 on Fe.50 block using Agfa D4 Pb ↓	150 kV 20 mA SFD 80 cm 0.8 min (0'48")	150 kV 4 mA SFD 80 cm 4.0 min (4'00")	150 kV 3 mA SFD 80 cm 4.6 min (4'36")	150 kV 4 mA SFD 80 cm 4.9 min (4'54")
<b>Adjustment for same Ug</b> SFD · Ø / Ø <sub>Smart</sub> (Ug <sub>.50</sub> ≅ .043 mm) ↓	150 kV 20 mA SFD 135 cm 2.3 min (2'18")	150 kV 4 mA SFD 34 cm 0.7 min (0'42")	150 kV 3 mA SFD 73 cm 3.8 min (3'48")	150 kV 4 mA SFD 80 cm 4.9 min (4'54")
<b>KV discrepancy</b> (see para.3) ↓	0% 150 kV	0% 150 kV	-3% 150+3%≅155 kV	-6% 150+3%=159 kV
<b>Adjustment for same Co</b> (time from diagram below) ↓	<b>150 kV 20 mA</b> <b>SFD 135 cm</b>	<b>150 kV 4 mA</b> <b>SFD 34 cm</b>	<b>155 kV 3 mA</b> <b>SFD 73 cm</b>	<b>159 kV 4 mA</b> <b>SFD 80 cm</b>
<b>Equivalent Radiographs</b> ←	<b>2.3 min (2'18")</b>	<b>0.7 min (0'42")</b>	<b>3.2 min (3'12")</b>	<b>3.7 min (3'42")</b>
<b>Same Co and same image</b> <b>distortion on film edge</b> (SFD = 100 cm)	150 kV 20 mA (Ug <sub>.50</sub> ≅ .057 mm) 1.3 min (1'18")	150 kV 4 mA (Ug <sub>.50</sub> ≅ .015 mm) 6.1 min (6'06")	155 kV 3 mA (Ug <sub>.50</sub> ≅ .031 mm) 6.0 min (6'00")	159 kV 4 mA (Ug <sub>.50</sub> ≅ .034 mm) 5.8 min (5'48")

kV	Rel.ExpT (%)
125	275
135	180
145	140
150	100
155	80
165	65
175	55

Diagram on the left is intended to calculate Exposure Time for kV variation in the range 150±15% in order to maintain density 2.0 on steel block .50 (thickness 12.7 mm). This diagram is obtained experimentally using Eresco 65MF2, Agfa D4, lead screens 0.027 thick and SFD 120 cm. Rel.ExpT 100% corresponds to 12.5 mA·minutes.

### 6. Introduction of alternate film of other manufacturer in a Certified Film System

**Parameters:** Contrast (**Co**), Penetrator Detectability (**PeD**) and Crack Detectability (**CrD**).

Normally Certified Film System (CFS) from one manufacturer only is used. However technical reason for use of Alternate Film System (AFS), where film and chemistry manufacturers are different, may be the following:

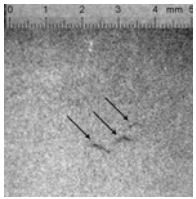
- film manufacturing artifacts can be occurred with manufacturer unable to supply same class films for many months (typically concerning not-large production film types);
- film manufacturers do not produce any size and/or package for any film type;
- generally processors with different chemicals are not available (and practical) for a radiographic facility.

Generally no specific requirement forbids AFS but there is not standard procedure substantiating a satisfying AFS use. Typical undefined requirement is supplied by ASTM E2104 para.6.2.2

“Only film system having cognizant engineering organization approval or meeting requirements of Test Method E 1815 Class I, Class II, or special shall be used.” ASTM E1815 and equivalent EN 584-1 standards classify film and associated processing using objective signal and noise parameters as Gradient G at net density 2.0 and 4.0 (signal), Granularity  $\sigma_D$  at net density 2.0 (noise),  $G/\sigma_D$  (signal to noise ratio). Unfortunately G,  $\sigma_D$  and  $G/\sigma_D$  cannot be easily measured by RT facility and, practically, this kind of classification is applicable to CFS only where manufacturer measures performances of its proper Film System. Otherwise which practical criteria should be followed by a RT Level 3 of cognizant engineering organization to approve an AFS ?

First of all a good technical reason is necessary to adopt an AFS, otherwise CFS is preferable: e.g. ASTM E1815 special or EN 584-1 Class 1 films in lead vacuum package should be used for high sensitivity on low steel thickness where fine cracks are possible; until 2004 the only film standard produced in lead vacuum package has been Fuji Ix25; being Avio provided with Agfa CFS, what about Fuji Ix25 performances in Agfa processing ?

So five D4, five D3, five D2 and five Ix25 were produced on cracked steel welded specimen 5 mm thick using Yxlon Smart 225X. **Fig.10** shows crack image and exposure parameters.

<b>Fig.10</b> 	kV	mA	SFD (cm)	Lead screen (see Note 1)	Density range on cracked area	Exposure Time for			
						D4	D3	D2	Ix25
	160	4	130	0.027 mm	from 2.85 to 3.05	1'44"	2'20"	4'15"	4'15"
<b>Note 1</b> - In order to simulate same tighten screen-film contact, Agfa D2 has been introduced in lead screen and envelope normally used for D4 or D3; then it was placed in rigid cassette; D4, D3 and Ix25 in standard lead vacuum pack was introduced in the same rigid cassette being used for D2 to assure same conditions.									

EN 462-1 13EN wire penetrometer, TAM/ASTM E1742 .20 step-hole penetrometer and shim 2 mm thick were placed on specimen to measure image quality. Films were identified by lead numbers from 1 to 20 randomly so that examiner cannot recognize film type. **Fig.11** shows contrast between thickness 5 and 7 mm on 20 films.

<b>Fig.11</b> Film	Sample film 1			Sample film 2			Sample film 3			Sample film 4			Sample film 5			Co Average $\Delta$
	5	7	$\Delta$	5	7	$\Delta$	5	7	$\Delta$	5	7	$\Delta$	5	7	$\Delta$	
D4	2.88	1.99	0.89	3.02	2.07	0.95	2.95	2.02	0.93	3.00	2.05	0.95	2.96	2.04	0.92	0.93
D3	2.95	1.93	1.02	2.88	1.89	0.99	2.94	1.92	1.02	2.95	1.93	1.02	2.93	1.91	1.02	1.01
D2	2.88	1.87	1.01	2.99	1.93	1.06	2.96	1.90	1.06	3.01	1.93	1.08	2.92	1.87	1.05	1.05
Ix25	2.87	1.85	1.02	2.88	1.85	1.03	2.84	1.83	1.01	2.93	1.92	1.01	2.88	1.85	1.03	1.02

**Fig.12** shows evaluation of detectable wires (nw) and holes (nh) by two examiners (see Note 2 & 3).

<b>Fig.12</b> Film	Sample film 1			Sample film 2			Sample film 3			Sample film 4			Sample film 5			PeD average EPS
	nw	nh	EPS %	nw	nh	EPS %	nw	nh	EPS %	nw	nh	EPS %	nw	nh	EPS %	
D4	4.50	2.00	3.2	4.50	2.00	3.2	4.50	2.00	3.2	4.75	2.25	3.0	4.25	2.50	3.0	3.1%
D3	5.00	2.00	3.1	5.25	2.50	2.8	5.00	2.75	2.7	5.00	2.25	2.9	5.25	2.50	2.8	2.8%
D2	5.50	3.00	2.5	5.50	2.75	2.6	5.00	2.50	2.8	5.25	2.75	2.6	5.25	2.50	2.8	2.7%
Ix25	5.25	2.75	2.6	5.50	2.75	2.6	5.25	2.75	2.6	5.25	2.50	2.8	5.50	3.00	2.5	2.6%

**Fig.13** shows evaluation of crack detection by two examiners (see Note 2 & 4).

<b>Fig.13</b> Film	Sample film 1	Sample film 2	Sample film 3	Sample film 4	Sample film 5	CrD ave.score
	score	score	score	score	score	
D4	2.75	3.50	2.75	4.25	2.75	3.20
D3	10.75	8.25	9.50	10.75	9.50	9.75
D2	15.50	13.00	13.00	16.75	11.75	14.00
Ix25	18.50	17.75	9.50	14.75	18.50	15.80

Results from Fig.11, Fig.12 and Fig.13, show that FujiIx25+AgfaG135 AFS can be considered as equivalent to AgfaD2+AgfaG135 CFS for specific Avio application concerning high sensitivity on low steel thickness where fine cracks are possible: to be noted in fact that Fuji Ix25 performances are always better than Agfa D4 and D3.

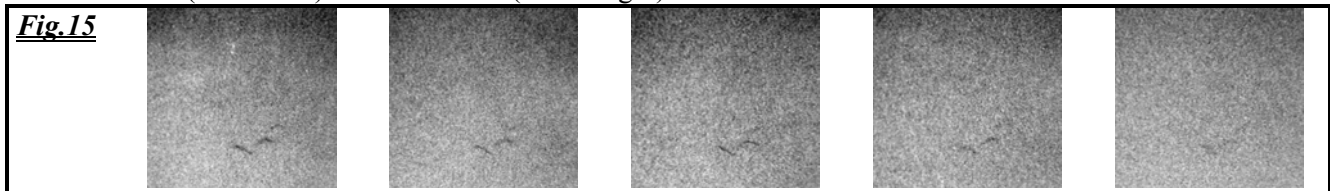
This confirms results reported during 15wcdnt in Rome in 2000 where Agfa D2 (named β1) and Fuji Ix25 (named α1) supplied the best equivalent performance among 14 film types processed by 3 different chemistry. To be noted that, where AFS is used, periodical performance check is important because film manufacturer cannot monitor possible variation of chemistry produced by other manufacturer: in the case of CFS manufacturer is continuously monitoring his proper Film System according to both ASTM E1815 and EN584-1.

Note 2 – Two different skilled radiologists examined the set of 20 films. Values in the tables (nw, nh and score) are averages between evaluations of two radiologists on the same film.

Note 3 – As detailed in Fig.14, Equivalent Penetrameter Sensitivity EPS for step-hole penetrameters has been computed according to ASTM E1025 App.X1.1; for wire penetrameters same computation has been used after determination of equivalent hole diameter and thickness of step-hole penetrameter according to ASTM E747 App.X1.1. Values for **PeD** in Fig.12 are averages between  $EPS_w$  and  $EPS_H$ .

<u>Fig.14</u> X=5mm			X=5mm, T=0.1016 mm T penetrameter thickness		
$EPS_w = \frac{100}{X} \cdot \sqrt[4]{1.193 \cdot d^3}$			$EPS_H = \frac{100}{X} \cdot \sqrt{\frac{T \cdot h}{2}}$		
nw = number of wires	min wire $\varnothing$ d (mm)	$EPS_w$	nh = number of holes	min hole $\varnothing$ h (mm)	$EPS_H$
4	0.100	3.7%	1	1.016	4,5%
5	0.080	3.1%	2	0.508	3,2%
6	0.063	2.6%	3	0.254	2.2%

Note 4 – Following example details **CrD** score system taking into account that Group 1 shows the best crack detection: Gr.1, 3 films, each film score  $19=(20+18)/2$  – Gr.2, 4 films, each film score  $15.5=(17+14)/2$  - Gr.3, 2 films, each film score  $12.5=(13+12)/2$  – Gr.4, 10 films, each film score  $6.5=(11+2)/2$  - Gr.5, 1 film, score 1. Fig.15 gives different crack detection levels from EN 584-1 Class 1 (on the left) to Class 4 film (on the right).



**Conclusions:** So question «Is "Self-calibration" applicable to radiographic system too?» can be answered YES.

Practically no special device or instrument is necessary in addition to what is standard for a good radiographic facility. Cooperation with film and X-ray equipment manufacturer is very important also to have available reliable pre-exposed film strips for processing control and reference equipment for kV discrepancy evaluation. In this connection Avio radiologists should thank Italian GE Inspection Technologies Representative for more than 15 years of continuous and effective technical cooperation using both Agfa films and Seifert equipment.

**References:** Following documents are referenced in this paper:

ASTM E747 Design, Manufacture and Material Grouping Classification of Wire IQI Used for Radiology

ASTM E1025 Design, Manufacture and Material Grouping Classification of Hole-Type IQI Used for Radiology

ASTM E1165 Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging

ASTM E1742 Radiographic Examination

- ASTM E1815 Classification of Film Systems for Industrial Radiography
- ASTM E2104 Radiographic Examination of Advanced Aero and Turbine Materials and Components
- EN 462-1 IQI (wire type) – Quality image determination
- EN 584-1 Industrial radiographic film - Classification of film systems for industrial radiography
- EN 584-2 Industrial radiographic film - Control of film processing by means of reference values
- EN 12543-4 Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing – Part 4: Edge method
- EN 12544-1 Measurement and evaluation of the X-ray tube voltage – Part 1: Voltage divider method
- EN 12544-2 Measurement and evaluation of the X-ray tube voltage – Part 1: Constancy check by the thick filter method
- “Evaluation of Film System by a Radiographic Facility” Bianchi, Liscio, Piazza, Baratta, 15wcn dt, Rome 2000.