COMPUTED RADIOGRAPHY TECHNIQUE FOR WELD INSPECTION: THE PROCESS OF QUALIFICATION AND VALIDATION OF INSPECTION PROCEDURES IN BRAZIL

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ABSTRACT

Actually, until nowadays Computed Radiography (CR) testing procedures are still based on experiments, trial and error, as a consolidated methodology to choose parameters, as in conventional radiography, is not in place yet. PETROBRAS, the Brazilian Energy Company, has worked in order to implant Computed Radiography for in-site weld inspection, running a big project in a partnership with the Federal University of Rio de Janeiro (UFRJ), Carestream Health, GE Inspection Technologies, Dürr NDT, and some Brazilian Inspection Companies: ArcTest – Technical Services in Maintenance and Inspection and Qualitec – Engineering with Quality. This work presents the results delivered by the CR systems found in the market, applied to welding inspections using the double wall double image technique (DWDI). Radioactive sources and X-Ray equipment were used.

Key words: Computed Radiography, Weld Inspection, Qualification and Validation of Inspection Procedures

INTRODUCTION

In order to qualify and validate procedures to inspect welded joints using computed radiography (CR), PETROBRAS has coordinated a big project, where several uneven welded test specimens were manufactured, and then invited CR System manufacturers, which sealed partnerships with Brazilian inspection companies to begin the sample testing. The results delivered by each system used define which system would be able to provide field services in PETROBRAS' worksites. The project was divided into three phases:

1- Preparation of inspection procedures according to PETROBRAS' internal standards;
2- Procedure qualification and preparation of the NDT Procedure Qualification Records (RQPEND – Registro da Qualificação de Procedimento de END);
3- Reproduction of lab conditions in field testing, using the documents previously prepared.

The following standards was used as standard criteria: ASME B31.3 – Process Piping , ASME Boiler and Pressure Vessel Code, Section V and PETROBRAS N-2821 (Non-Destructive Testing – Computed Radiography of Welded Joints), BS EN 14784 part 1 (Non-Destructive Testing – Industrial Computed Radiography with Storage Phosphor Imaging Plates – Part 1: Classifications of Systems), ASTM E-2445 (Standard Practice for Qualification and Long-Term Stability of Computed Radiology Systems) and ASTM E-2446 (Standard Practice for Classification of Computed Radiology Systems). The approved systems must meet the requirements of these Standards within the inspected diameter and thickness range.

In the initial phase, radioactive sources (Ir-192 and Se-75) and X-Ray equipment were used. Only satisfactory results acquired in a previous phase would allow the participation in the next step.

1. THE PROJECT– PHASES OF THE PROCESS

The PETROBRAS project was divided in three phases, as mentioned, and each one will be summarily described.

1.1. Phase 1 - Preparation of Inspection Procedures According to PETROBRAS' Internal Standards

In the first phase of the project, five service providing companies participated, as well as five manufacturers of CR systems. Partnerships were established between manufacturers and contractors, without interference of PETROBRAS. Table I shows the relation between companies, computed radiography systems (scanners and imaging plates) and type of source (X or gamma rays) used. Table II shows the essential characteristics of the scanners used.

Table I – Providers and Radiography Systems used in Phase 1

Provider	CR System: scanner and IPs	Supplier	Source
ArcTest	DenOptix / IP Gendex HR	Gendex	X-ray - Seifert Mobile 160kV
	ACR-2000i / IP KODAK HR	KODAK	
Brasitest	ACR-2000i / IP KODAK HR	KODAK	X-ray - COMET
NDT do Brasil	DR-1400 / IP CIT SHR	CIT	X-ray - CIT / CP 160kV - 78R
Qualitec	CR50P / IP GE IPS	GE-IT	X-ray - Seifert Eresco MF3 series
			Ir-192
			Se-75
Top Check	HDCR35 Dürr / IP Dürr blue HD	Dürr	X-ray - not informed
			Ir-192
			Se-75

Table II – Essential features of the scanners used

Scanner	Laser spot size (ĩm)	Pixel size (ĩm)	Range bits
DenOptix	Not informed	170	8
ACR2000i	87,5	73	12
DR-1400	12,5	20	16
CR50P	50	50	15
HDCR35	12,5	21	16

The images obtained by the service providers were evaluated by PETROBRAS and UFRJ, according to the following parameters: radiographic sensitivity, by IQI contrast (wire or hole), basic spatial resolution (SR_b), through duplex wire IQI, and normalized signal to noise ratio (SNR_N) through an specific software called ISee!.

Each partnership received 5 test specimens in the form of circumferentially welded pipes. Table III shows the dimensions of the pipes and the requirements of radiographic quality for approval.

Table III – Requirements of radiographic quality for the images in phase 1

Sample	Dimensions (mm)		Contrast Sensitivity			SR_b (µm)	SNR_N
	Ø	Thickness + reinforcement (ASME B31.3)	Essential wire (EN/DIN)	Essential wire (ASTM)	Essential hole		
S1	48,5	5,08+1,5	W12	W6	15-2T	65 - 12D	>70
S2	60,3	5,54+1,5	W12	W6	15-2T	65 - 12D	>70
S3	60,3	11,07+3,0	W10	W8	20-2T	80 - 11D	>60
S4	88,9	5,49+1,5	W12	W6	15-2T	65 - 12D	>70
S5	88,9	7,62+3,0	W11	W7	17-2T	80 - 11D	>60

Note: isotopes using as sources, for any sample, the SR_b is required 160 µm-9D

Table IV shows the average of the results obtained for the 5 test specimens tested, in function of the partnership and source. Results that do not achieve the conditions of the reference standards are highlighted in red.

Table IV – Results of sensitivity, spatial resolution and SNR_N in phase 1

Company	CR System	Source	Contrast Sensitivity Wire / hole					SR_b (µm)					SNR_N				
			S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Arctest	Gendex	X-ray	12	12	--	13	11	100	100	--	100	100	41	48	--	47	64
	Kodak	X-ray	12	12	--	12	12	100	80-100	--	100	100	88	86	--	90	101
Qualitec	GE	X-ray	12	12	0-10	12	13	100	100	130	100	100	132	150	173	194	138
		Ir-192	10	0-12	0-10	10	11	200	200	200	200-250	250	62	75	70	69	73
		Se-75	13-11	11	0	10	11-10	160-200	200	200	250	200	75	74	73	60	77
NDT Brasil*	CIT	X-ray	6-7	6	7	6	7	65-80	80	80	80	80	100	95	84	83	84
Brasitest	Kodak	X-ray	5	5	6	5	6	100-130	100-130	100-130	100-130	100-130	78	79	80	82	88
Top Check**	Dürr***	X-ray	15-1T	15-2T	17-2T	15-1T	17-2T	65	50	65	50	65	97	130	105	123	104
		Ir-192	15-4T	15-4T	20-2T	15-4T 15-2T	17-2T	160-200	160-200	200	160	160	40	35	34	40	50

		Se-75	15-4T 15-2T	15-4T 15-2T	20-4T 20-2T	15-2T	17-2T	100-130	160-200	130-200	160	160	48	42	54	43	40

Note: * The radiographs in this phase were performed in England by CIT itself.
** The radiographs in this phase were performed in Germany by Dürr itself.
***Dürr used the first HDIP available in the market during these tests.

Figure 1 shows images related to the S2, obtained with the Dürr CR System, using x-ray equipment (1 (a)), Se-75 (1 (b)) and Ir-192 (1 (c)). The system achieved all the requirements in 1 (a) did not reach the SNR_N in 1 (b) and failed in SR_b and SNR_N in 1 (c).

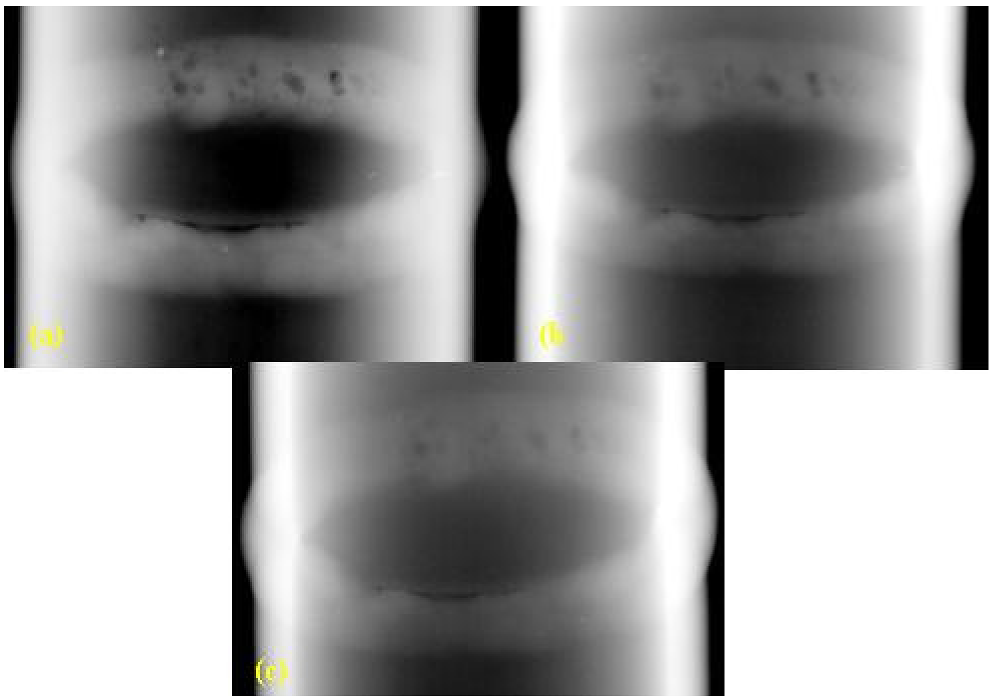

Figure 1 – Effect of the source used: (a) X-rays; (b) Se-75; (c) Ir-192.

The first phase of the project aimed to select the CR systems that would be used in the subsequent stage. The criteria used were based on values of sensitivity, resolution and normalized signal to noise ratio. Systems that were approved in at least two of these three quality requirements were classified to stage 2.

The Gendex system was not adequate to inspect welds for being applied to the odontological segment, presenting characteristics that impede the compliance with requirements of resolution and SNR_N. The major limiter of this system is just the low signal to noise ratio attainable. The SNR_N parameter is strictly related to the sensitivity of detection of defects and interferes significantly in the detectability (1).

The use of isotopes has presented limitations in function of the source size. It was found that although the system used by Dürr has completely met the normative requirements with the use of X-rays, it obtained partial approval (in two requirements) in only 35% of attempts with gamma rays. A single attempt with Se-75 was completely successful. However, the GE CR system (CR50P scanner and high-quality IPs) obtained partial approval in tests with X-rays and in only 30% of the cases with gamma rays. For this system there was no case of full compliance with the normative requirements, and with gamma rays the performance was inferior and unsatisfactory.

It was still found that only Computed Radiography systems which made use of X-ray sources, high-quality phosphor plates and scanners with the maximum size of the player of 12.5 µm have achieved full approval in all of the normative requirements. This was the case of CIT / NDT and Dürr / Top Check. This approval, however, has not happened in 100% of the cases, which shows that it takes more experience with the technique.

1.2. Phase 2 - Procedure Qualification and Preparation of the NDT Procedure Qualification Registers

Top Check and NDT do Brasil have declined the project, the use of isotopes was not allowed and the Gendex system was not approved. Due to these changes, new connections were established among the participants, as shown in Table V.

Table V – Providers and Radiography Systems used in Phase 2

Provider	CR System:	Supplier
ArcTest	ACR-2000i / IP KODAK HR	KODAK
	HDCR35 Dürr / IP Dürr blue HD	Dürr
	DR-1400	CIT
Brasitest	ACR-2000i / IP KODAK HR	KODAK
Qualitec	CR50P / IP GE IPS	GE-IT

In this phase, 4 sets of 21 spools were made, each one with 9 joints, shown in Figure 2, considering that the suppliers should radiograph 2 joints of each spool (one pipe x pipe joint and one pipe x connection joint). Table VI shows the dimensions of these new test specimens and radiographic quality requirements for approval. Only the ranges of diameter and thickness in which all requirements were met would be inspected in Phase 3, of field tests.

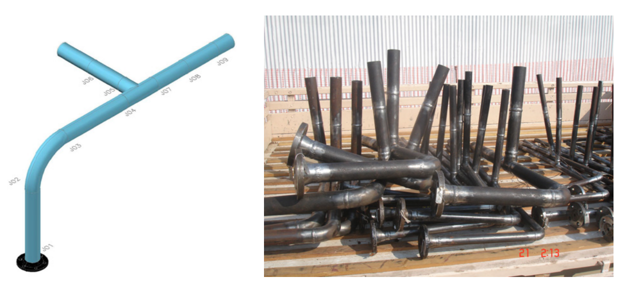

Figure 2 – Spool set.

The evaluation of the images was performed in a similar manner to what was done in phase 1, involving even the same individuals.

Table VI - Requirements of radiographic quality for the images in phase 2

Dimensions			Contrast Sensitivity			SR_b (µm)	SNR_N
Ø (in)	sch	Thickness + reinforcement (ASME B31.3) (mm)	Essential Wire (EN/DIN)	Essential Wire (ASTM)	Essential Hole		
½"	80	3,73+1,5	W13	W5	12-2T	65 – 12D	>70
½"	160	4,76+1,5	W13	W5	12-2T	65 – 12D	>70
¾"	40	2,87+1,5	W13	W5	12-2T	65 – 12D	>70
¾"	80	3,9+1,5	W13	W5	12-2T	65 – 12D	>70
¾"	160	5,56+1,5	W12	W6	15-2T	65 – 12D	>70
¾"	XXS	7,82+3,0	W11	W7	17-2T	80 – 11D	>60
1"	80	4,55+1,5	W13	W5	12-2T	65 – 12D	>70
1"	160	6,35+3,0	W12	W6	15-2T	80 – 11D	>70
1"	XXS	9,09+3,0	W11	W7	17-2T	80 – 11D	>60
1 ½"	80	5,08+1,5	W12	W6	15-2T	65 – 12D	>70
1 ½"	160	7,14+3,0	W11	W7	17-2T	80 – 11D	>60
1 ½"	XXS	10,15+3,0	W10	W8	20-2T	80 – 11D	>60
2"	40	3,91+1,5	W13	W5	12-2T	65 – 12D	>70
2"	80	5,54+1,5	W12	W6	15-2T	65 – 12D	>70
2"	160	8,74+3,0	W11	W7	17-2T	80 – 11D	>60
2"	XXS	11,07+3,0	W10	W8	20-2T	80 – 11D	>60
2 ½"	40	5,16+1,5	W12	W6	15-2T	65 – 12D	>70
2 ½"	80	7,01+3,0	W11	W7	17-2T	80 – 11D	>60
3"	40	5,49+1,5	W12	W6	15-2T	65 – 12D	>70
3"	80	7,62+3,0	W11	W7	17-2T	80 – 11D	>60
3"	160	11,13+3,0	W10	W8	20-2T	80 – 11D	>60

The results obtained in phase 2 are presented in partnership (CR system – contractor) in Table VII. The values of contrast sensitivity, SR_b and SNR_N achieved for all spools are shown. The X-ray equipments were the same of the previous phase. The CIT-ArcTest partnership did not have conditions to test all samples by lack of availability of the CR system. Thus, its results will not be described. Disapproved results are indicated in red.

The second phase of the project aimed to select the ranges of diameter and thickness inspectable by each CR system participating in the project. In this phase, comparisons with the conventional radiography, in terms of detectability, were not made either, and the criterion of approval was only due to the standard requirements.

All partnerships created the Procedure Qualification Records related to each spool inspected, and were subjected to performance evaluation. This evaluation was carried out through follow-up of PETROBRAS and UFRJ representatives directly at the facilities of the service providers, with witness of the execution of the tests under the conditions expressed in the registers.

Table VII shows that the best results in terms of resolution were obtained with use of the Dürr system, but the Kodak system, also operated by ArcTest presented the best overall performance. The company had less time to become familiar with the Dürr system, and it was reflected in the final results. Although Brasitest used the same Kodak system, it presented a much lower performance due to the size of the focal source it has worked with. During the performance of the tests in phase 2, the X-ray equipment presented problems, with only the possibility of working with the coarse focus (4.5 mm). As a result, its results were highly jeopardized.

The results of the GEIT-Qualitec partnership failed enough in terms of resolution, a variable that has been proving to be the major obstacle for most of the CR systems in the market.

According to the previous experience of PETROBRAS (2), the partnerships were enabled to work with the ranges of diameter and thickness indicated in Table VIII, even if the resolution requirements had not been achieved in phase 2 (if the difference was only one pair). The spools were separated by classes of thickness, according to requirement of PETROBRAS Standard N-2821, for purpose of validation with the conventional radiography.

Table VII - Results of sensitivity, SR_b and SNR_N for each partnership

Samples			Essential wire (EN/DIN)				SR_b (µm)				SNR_N			
Ø (in)	sch	t (mm)	1 (DIN)	2 (DIN)	3 (ASTM)	4 (DIN)	1	2	3	4	1	2	3	4
½”	80	3,73	W13	W13	W5 – W6	W11	80	65	100	80–100	95	72	110	65
½”	160	4,76	W13	W13	W5	W11	80	65	100 – 130	100	103	69	131	77
¾”	40	2,87	W13	W12	W4 – W5	W11	80	65	80 – 160	80–65	85	87	122	130
¾”	80	3,9	W13	W13	W5 – W6	W11	80	100	100	100	97	59	113	79
¾”	160	5,56	W13	W12	W6 – W7	W11	80	80	100	100	104	82	117	107
¾”	XXS	7,82	W11	0	0	W10 – 0	80	80	100	100	124	87	92	96
1”	80	4,55	W13	W13	W5 – W6	W12 –W11	80	65	80–100	100	125	92	115	91
1”	160	6,35	W13	W12	W6 – W7	W11 – 0	80	80	100	100	126	83	139	124
1”	XXS	9,09			0 – W7	W10 – 0			100 – 130	100			94	90
1 ½”	80	5,08	W13	W12	W6	W13 – W12	80	100	100	80–65	116	70	80	135
1 ½”	160	7,14	W13-W12	W11	W6	W12	80	80	100	100	123	85	107	109

1 ½"	XXS	10,15			W7 – W8	W10			100	100			83	115
2"	40	3,91	W13	W13	W4 – W5	W13	80	80	100 – 130	65	110	78	101	210
2"	80	5,54	W12	W12	W6 – W7	W13 –W12	80	80	100	80	125	89	120	141
2"	160	8,74			W7	W12			100 – 130	100–130			87	121
2"	XXS	11,07			W7 – W8	W11 – W9			100 – 130	100–130			94	114
2 ½"	40	5,16	W13	W12	W6 – W7	W13	80	100	100	100	123	70	118	143
2 ½"	80	7,01	W12-W11	W11	W6 – W7	W12	80	100	100 – 130	100	130	77	114	126
3"	40	5,49	W13	W12	W6 – W7	W13 – W12	80	100	100 – 130	80	124	79	93	187
3"	80	7,62	W12	W11	W6 – W7	W12	80	130	100	100	139	68	110	143
3"	160	11,13			W7 – W9	W10			160	100–130			65	122

Notes: Partnerships - 1 = Kodak and ArcTest, 2 = Dürr and ArcTest, 3 = Kodak and Brasitest, 4 = GEIT and Qualitec

Table VIII - Ranges of diameter and thickness approved for each CR system

Spools																
½"	¾"	¾"	2"	½"	¾"	¾"	1"	1"	1 ½"	1 ½"	1 ½"	2"	2 ½"	2 ½"	3"	3"
80	40	80	40	160	160	XXS	80	160	80	160	XXS	80	40	80	40	80
Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest		Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest	Kodak System +ArcTest
Dürr System +ArcTest	Dürr System +ArcTest		Dürr System +ArcTest	Dürr System +ArcTest	Dürr System +ArcTest	Dürr System +ArcTest	Dürr System +ArcTest	Dürr System +ArcTest		Dürr System +ArcTest		Dürr System +ArcTest		Dürr System +ArcTest		
			GEIT System +Qualitec						GEIT System +Qualitec	GEIT System +Qualitec	GEIT System +Qualitec	GEIT System +Qualitec		GEIT System +Qualitec	GEIT System +Qualitec	GEIT System +Qualitec
								Kodak System +Brasitest		Kodak System +Brasitest						Kodak System +Brasitest

Yellow	Kodak System +ArcTest
Green	Dürr System +ArcTest
Cyan	GEIT System +Qualitec
Black	Kodak System +Brasitest

Due to internal order matters, Brasitest declined to participate in the third phase.

1.3. Phase 3 - Reproduction of Lab Conditions in Field Testing

In this phase, the companies have carried out field tests at a site where a scenario that reproduced unfavorable conditions of scattered radiation was purposely set up. This procedure aimed to simulate critical field conditions for the computed radiography, and was repeated for all partnerships. Figure 3 shows the test site.

Figure 3 – Test performance site

Among the 4 sets of 21 spools inspected in phase 2, only one of them was chosen for each range of diameter and thickness to be tested in phase 3. All joints of these samples were radiographed, through the conventional technique and with the use of X-rays and gamma ray sources.

For tests with CR, the contractors followed the same parameters defined in the registers. PETROBRAS team determined which would be the first joint to be radiographed and the result was compared, in terms of detectability, with the corresponding radiographic film. Simultaneously, the parameters of basic spatial resolution (SR_b), contrast sensitivity and normalized signal to noise ratio (SNR_N) were evaluated. If there was full compliance, the contractor continued with the inspection of the joints in that spool, otherwise, new exposures, with parameter adjustments, were performed until the detectability equivalent to the conventional technique was achieved. This procedure was repeated for the each range of diameter/thickness tested.

It is noteworthy that the detectability was not evaluated in phases 1 and 2 of the project, and that the adjustments made in phase 3 to ensure the validation of results were based on the previous experience (2), and performance of the technique observed for each system during the field tests.

Due to the good repeatability conditions achieved, it was decided that the duplex wire IQI, essential for the determination of the SR_b would be used only in the first joint of each spool. In this stage, the use of hole IQI was not allowed. The companies used wire IQI according to the EN/DIN standard. The images were evaluated by PETROBRAS.

The validation process followed the provisions of PETROBRAS Standard N-2821, which provided that for each combination of diameter and thickness, a number of 30 joints are inspected by CR, with complete equivalence in detectability with the conventional radiography. Met this condition, the inspection procedure is considered validated for the dimensional range tested. For the DWDI technique, the thickness ranges requiring 30 joints are: up to 6.0 mm, between 6.0 and 12.0 mm (including), between 12.0 and 20.0 mm (including), between 20.0 and 25.0 mm (including) and greater than 25.0 mm. The joints to be inspected were chosen by PETROBRAS team with basis on the results of the conventional radiography and in a manner to comply with the required sampling.

1.3.1. Results

Table IX shows the parameters that allowed the validation of the procedures in comparison with the conditions adopted in conventional radiography.

Table IX - Validation of the inspection procedures: test parameters

Ø (in)	Sch	t (mm)	Conventional radiography		Computed Radiography (CR)					
					Kodak+ArcTest		Dürr+ArcTest		GEIT+Qualitec	
			kV	Exp (mA.min)	kV	Exp (mA.min)	kV	Exp (mA.min)	kV	Exp (mA.min)
½"	80	3,73	120	19,8	130	9,0	140	12,0	--	--
¾"	40	2,87	110	19,3	130	9,0	140	15,0	--	--
¾"	80	3,9	120	19,8	130	9,0	140	15,0	--	--
2"	40	3,91	120	21,0	130	9,0	140	15,0	--	--
½"	160	4,76	130	19,3	140	10,0	140	16,7	--	--
¾"	160	5,56	130	21,0	140	10,0	160	16,7	--	--
¾"	XXS	7,82	150	26,8	180	14,4	180	10,7	--	--
1"	80	4,55	130	19,8	140	7,0	140	16,7	--	--
1 ½"	80	5,08	130	19,8	140	7,0	--	--	140	11,1
1 ½"	160	7,14	150	23,1	180	16,0	180	10,7	150	14,8
2"	80	5,54	130	21,0	140	13,5	160	20,8	140	11,1
2 ½"	40	5,16	130	17,5	140	7,0	--	--	NA	NA
2 ½"	80	7,01	150	23,3	190	12,0	190	12,0	150	11,1
3"	40	5,49	130	21,0	140	7,0	--	--	140	14,8
3"	80	7,62	150	26,8	200	12,0	--	--	160	14,8

Tables X, XI and XII show the comparison between the average values of resolution, contrast and normalized signal-to-noise ratio and intensity (gray level) achieved by the images approved in phase 2 and after exposure corrections in phase 3

Table X - Kodak CR System: comparisons between the results of phases 2 and 3

Ø (in)	Sch	t (mm)	SR_b phase 2	SR_b phase 3	Contrast phase 2	Contrast phase 3	SNR_N(*) phase 3	I(*) phase 3
½"	80	3,73	11D	10D	W13	W13	71	9800
¾"	40	2,87	11D	10D	W13	W13	70	12000
¾"	80	3,9	11D	10D	W13	W13	106	6000
2"	40	3,91	11D	10D	W13	W13	107	4700
½"	160	4,76	11D	10D	W13	W13	67	6500
¾"	160	5,56	11D	10D	W13	W12	78	7400
¾"	XXS	7,82	11D	10D	W11	W11	91	24000
1"	80	4,55	11D	10D	W13	W13	67	5500
1 ½"	80	5,08	11D	10D	W13	W12	97	6500

1 ½"	160	7,14	11D	10D	W13	W12	109	25000
2"	80	5,54	11D	10D	W12	W13-W12	93	5000
2 ½"	40	5,16	11D	9D	W13	W12-W11	88	4500
2 ½"	80	7,01	11D	10D	W12	W12	137	27000
3"	40	5,49	11D	10-9D	W13	W12	102	5700
3"	80	7,62	11D	10D	W12	W11	125	20000

Notes: (*) Values obtained after linearization of the images with LUT 12bitdelog – Scanner gain STD 120

Table XI - Dürr CR System: comparisons between the results of phases 2 and 3

Ø (in)	Sch	t (mm)	SR_b phase 2	SR_b phase 3	Contrast phase 2	Contrast phase 3	SNR_N phase 3	I phase 3
½"	80	3,73	12D	13D	W13	W13	135	11000
¾"	40	2,87	12D	12D	W12	W13	150	20000
¾"	80	3,9	10D	12D	W13	W13	145	16500
2"	40	3,91	11D	11-10D	W13	W13	140	13500
½"	160	4,76	12D	13D	W13	W13	165	19000
¾"	160	5,56	11D	12D	W12	W13-W12	160	29000
¾"	XXS	7,82	11D	11D	W11	W11	170	40000
1"	80	4,55	12D	12D	W13	W14-W13	150	16000
1 ½"	160	7,14	11D	10D	W11	W12	190	38000
2"	80	5,54	11D	11D	W12	W13	170	20500
2 ½"	80	7,01	10D	13D	W11	W12-W11	175	25000

Note: Scanner gain of 620V

Table XII-GEIT CR System: comparisons between the results of phases 2 and 3

Ø (in)	Sch	t (mm)	SR_b phase 2	SR phase 3	Contrast phase 2	Contrast phase 3	SNR_N phase 3	I phase 3
1½"	80	5,08	11D	11D	W13-W12	W13-W12	160	30000
1½"(*)	160	7,14	10D	11D	W12	W12	200	35000
2"	80	5,54	11D	11D	W13-W12	W13-W12	170	25000
2 ½"	80	7,01	10D	11D	W12	W12	160	25000
3"	40	5,49	11D	11D	W13-W12	W13	180	25000
3"	80	7,62	10D	11D	W12	W12	180	35000

Note: (*) Scanner gain of 650V. The other cases, 500V

Figures 4 to 6 show images obtained by each of the three systems for the same joint. Figure 7 shows the scanned radiographs related to these joints.

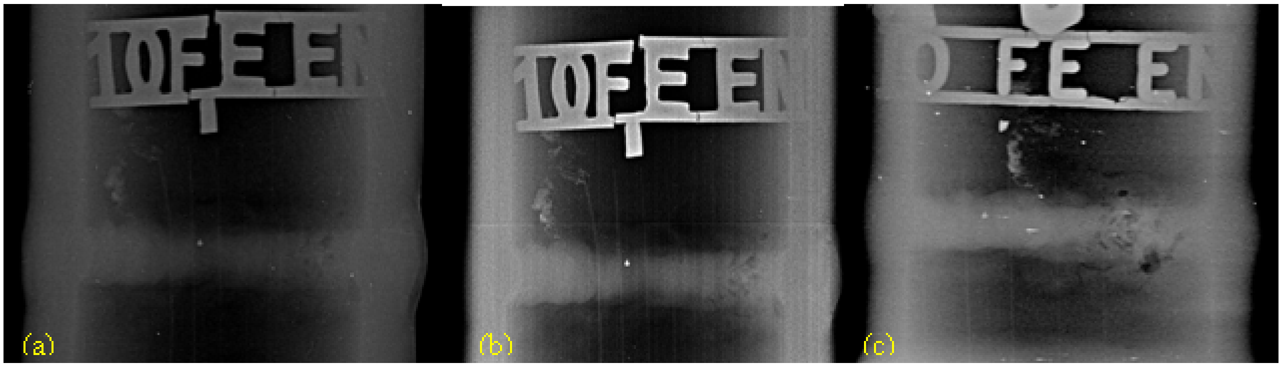

Figure 4 – *Spool* Ø1½" sch160, joint 09 position C: (a) Kodak System; (b) Dürr System; (c) GEIT System – in this case, the sample was slightly dislocated from de correct position. High-Pass Filter.

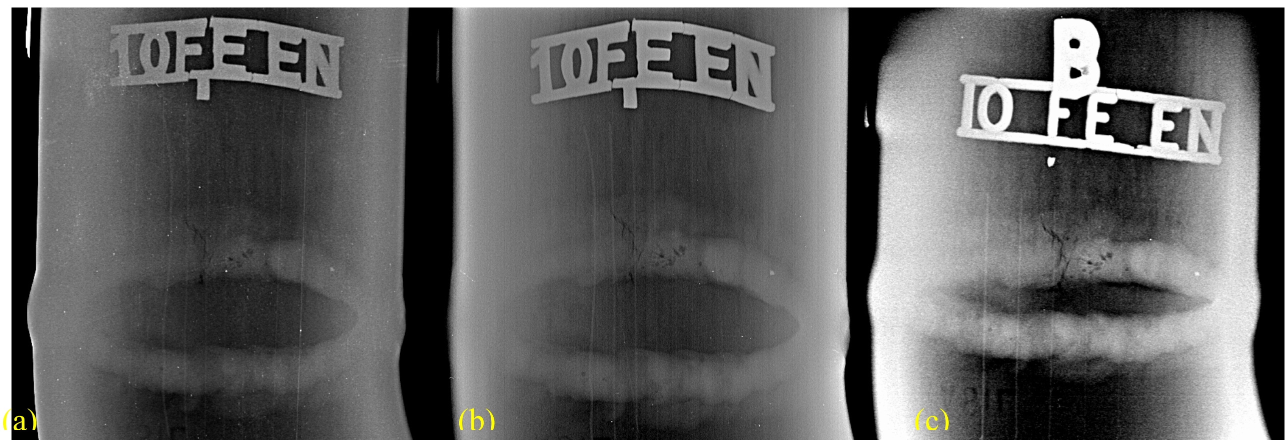

Figure 5 – *Spool* Ø2" sch80, joint 08 position B: (a) Kodak System; (b)Dürr System; (c) GEIT System. High-pass Filter

Figure 6 – *Spool* Ø2½" sch80, joint 03 position B: (a) Kodak System; (b)Dürr System; (c) GEIT System. High Pass Filter

The radiographs shown in figure 7 were scanned with FS50 GEIT scanner, pixel size of 50µm and dynamic range of 16bits.

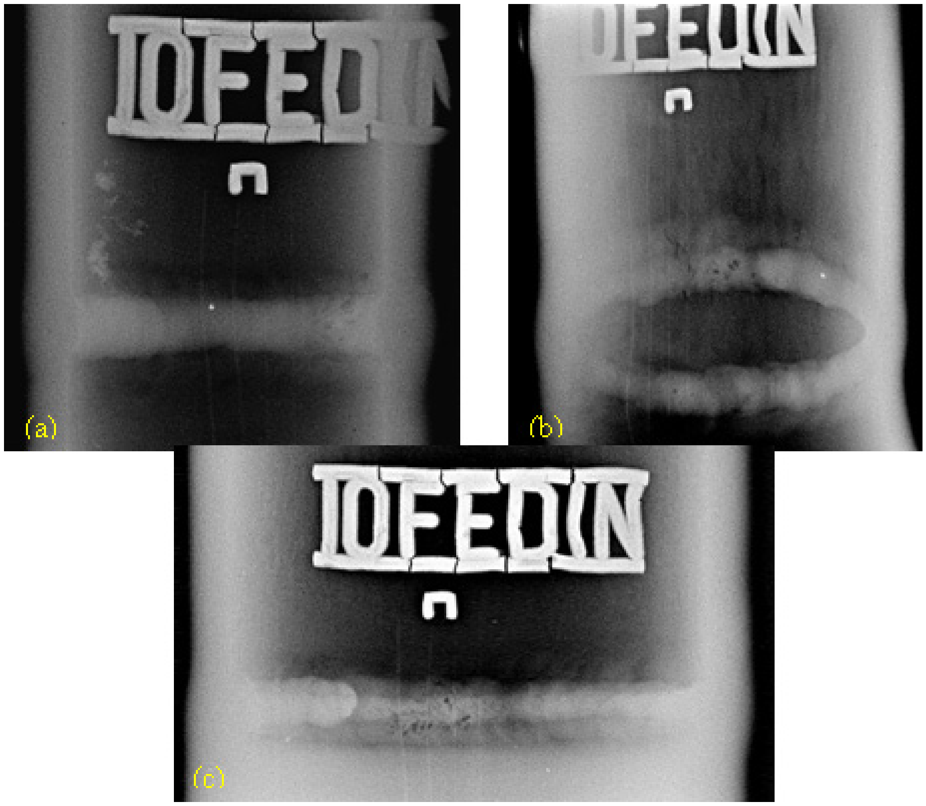

Figure 7 – Scanned Films: (a) Ø1½" sch160, J09C; (b) Ø2" sch80, J08B; (c) Ø2½" sch80, J03B. High-Pass Filter.

2. DISCUSSION OF RESULTS

The Kodak system, among the three systems tested in this stage, is the most efficient in terms of radiation absorption and extraction of the latent image from phosphor plates, therefore it achieved detectability equivalent for relatively low values of SNR_N (threshold about 95, average). On the one hand, there are, in general, more optimized conditions of exposure, but on the other hand the images are noisier. It is also reflected in the fact that the basic spatial resolution was jeopardized in 1 pair of wires in the field conditions (Table X), showing the negative influence of low energy radiations (scattering) that easily impress the IPs. The contrast, however, remained unchanged in most cases, but there were 6 situations in which one wire was lost (see Table X).

The linearised signal intensity is also a useful parameter for evaluation, although it is extremely dependent on factors such as the PMT (photomultiplier tube) gain. For the minor thickness ranges, the average values from 4700 to 12000 levels. In the range of 4-5,5 mm, the variation was minor, ranging from 4500 to 7400. For thicknesses up to 7mm, these values remained between 20000 and 27000. One factor that contributed to this less uniform behavior among the thinner spools, is related to the large variations of SNR_N in the samples of small diameter (below 1 "). This behavior has been shown to be typical of the Kodak system tested.

Table XI shows that Dürr system's behavior was more uniform than the Kodak's one. Spools in the range of the thinner thicknesses, including samples even with thickness about 4.7 mm, required energies of 140kV. Thicknesses in the range of 5.5 mm required energy of 160kV. The exposures ranged from 12 to 15mA.min, for the thinner spools, and stood at 16.7 mA.min for the range of 4-5,5 mm (except for the sample of Ø2" sch80, which required 20,8 mA. min). The thicker samples again required greater increase of energy, 180-190kV, and exposure between 10.7 and 12mA.min. The Table still shows that few parameter corrections have been made in relation to the laboratory test phase, with only exposure adjustments in most cases.

The Dürr system, with the best resolution among the three systems tested, requires more energy and exposure, on average, and generates images with minor contrast than the others. However, the defects are better defined and the final quality of the radiographs is a very strong point in favor of the system. Compared to the Kodak system, in the case of thicker samples, the system presented better overall performance, requiring more optimized energy and exposure values. The quality of the images, even in terms of visual contrast on the computer screen was superior.

In field conditions, the system gained 1 pair of wires in the SR_b or it has remained the same. In two cases, however, one pair was lost (Ø1 ½ "SCH160 and Ø2" sch40 - one image). Probably the problem was caused by the bad positioning of the arrangement and/or double wire IQI on the sample. In terms of contrast, 1 more wire was gained or it remained unchanged. The SNR_N threshold was of about 160 (Table XI). The reasons for this better performance in the field test were basically two: ArcTest team was more familiar with the system and new phosphor plates were used, only in this phase (HD IP PLUS).

It is also highlighted that this system worked with focal size of source greater than Kodak's (5,5mm vs 1mm), but despite that, the performance was satisfactory.

With the GEIT system only the spools with thickness from 5mm were inspected. Table XII shows that the in the range of 5-5.5 mm of thickness, the energy required was 140kV, whereas from 7mm this value was 150kV; except for the sample of Ø3", which required 160kV. In all cases the exposure ranged between 11.1 and 14.8 mA.min. It is noted that this system worked under more optimized conditions for the thicker samples, in terms of energy, compared to the other two. There were few corrections, basically in relation to the exposure.

Qualitec was advised to modify its procedure, with basis on the conclusions obtained at the beginning of the project, and changed the PMT gain for 500V (before this value was 450V) as well as and no longer used lead front screens. Thus, besides the reduction of exposure achieved in the case of the spool of Ø3" sch80, it obtained better resolution values in some cases (see Table XII). The contrast remained the same.

The SNR_N threshold was of 170 and the signal intensity remained between 25000 and 35000. Figures 4 to 6 show that the system generated intermediate definition images between the two previous cases, but with good contrast to noise ratio.

The general trend of CR followed what had already been observed by PETROBRAS (2), in other words, the values of energy required are greater (Table IX) than for conventional radiography. Regarding exposure, the comparison would be made possible only if, for the conventional technique, the KV values were corrected for the same levels used in the CR in each case.

In the comparison between the systems, in general, the Dürr one required more energy and exposure. For thinner samples this statement is completely valid. In the range of 4-5,5 mm, in some cases, Dürr and Kodak required the same energy levels, and the exposures for the Dürr system were always greater.

GEIT system required energy values comparable with those of Kodak, with higher exposures in general. The thicker samples constituted a change in the trend of behavior in the three systems, and in this case, Kodak presented the worst performance. GEIT stood out presenting the most optimized conditions.

According to the resolution requirements of PETROBRAS Standard N-2821, the values indicated in red in Tables X to XII would be all disapproved. However, the previous experience of the Company (2) showed that these requirements were quite rigorous. The trend towards rigor was observed globally, due to lack of experience, but now it is possible to make more realistic requirements. The recommendation is that the spatial resolution observed in the field does not exceed 100 µm (10D pair).

The exposure values required for spools with thickness almost equivalent were different in some cases, as a result of the different PODs of the defects existing in the joints. For different joints of a same spool this variation was observed for the same reason.

Detectability

A conventional radiographic inspection was performed in all welds of the spool set used in phase 3. For this inspection, the contractor has followed a qualified procedure elaborated by a level III professional and the radiograph report was given by a level II inspector, both certified by the National Qualification System in NDT.

In the detectability equivalence evaluation the films generated by X-rays were used. All images generated by each partnership in the field test were evaluated and reported by three inspectors certified in the National Qualification System in NDT as level II in radiography.

In the evaluation of the images the following methodology was used:

- IQI Evaluation – The image was used just as it was acquired, in other words, only contrast enhancements were made;
- Detection and identification of discontinuities - the high-pass filter of the Isee! program and contrast enhancement were used;
- Report - As criterion for acceptance of standard ASME B31.3.

The images generated by Kodak-ArcTest, Dürr-ArcTest and GEIT-Qualitec partnerships approved by PETROBRAS, presented results at least equivalent to conventional radiographs made with X-rays.

The images generated by the Dürr system, in most of the evaluations, presented detectability greater than the conventional radiography. The images of the discontinuities detected by the KODAK system present the best visual contrast on the computer screen (contrast to noise ratio). The results achieved by the GEIT system were very good, but, however, jeopardized by the scattering radiation generated in the set-up assembled by Qualitec.

It is important to highlight that in conventional radiography, the focal size adopted (X rays) was superior, in most cases, to the one applied with computed radiography, which did not work with isotopes. It indicates, despite the good results, the superiority of the conventional technique.

Regarding the radiographic technique of DWDI, the need to accomplish one exceeding exposure was observed, for elliptical radiography as well as for juxtaposed image.

3. CONCLUSIONS

Due to the advantages inherent to computed radiography (CR), PETROBRAS has sought to replace the conventional radiography in its works by the referred technique. However, this process requires a lot of study and experimental work.

The project ends with the qualification of 13 ranges of diameter and thickness for the Kodak-ArcTest partnership, 11 ranges for the Dürr-ArcTest partnership and 6 ranges for the GEIT-Qualitec partnership.

The partnerships could have qualified more comprehensive ranges, especially with the Dürr and GEIT systems, but they have failed in yield due to lack of technical bases in the understanding of computed radiography or familiarity with the systems. Certainly the results can be improved, but it depends on the contractor's efforts to become more qualified. PETROBRAS intends to invest in the CR technique and qualify more ranges of diameter and thickness, even in the scope of double wall single image techniques (DWSI) and single wall single image (SWSI).

The criteria of PETROBRAS Standard N-2821, as well as the international standards, need to be revised. For inspection of welds with computed radiography, a limit value of acceptable resolution for most of the situations found in the oil industry would be equal to 100 µm. The required values of SNR_N also need to be adjusted. Different thresholds of SNR_N for each system were observed. These thresholds ensure detectability equivalent with the conventional radiography within the bypass conditions tested in this project.

The CR detectability continuously improves as the radiation dose increases, and equivalence was achieved for energy values superior to those used for conventional radiography.

The images generated by the Kodak-ArcTest, Dürr-ArcTest and GEIT-Qualitec partnerships in all situations, presented results at least equivalent to conventional radiographs made with X-rays. Dürr System stood out in most of the evaluations, with detectability greater than in conventional radiography.

However, it is important to highlight that, in the conventional radiography, the focal size adopted (X-rays) was superior, in most cases, to the one applied with computed radiography, which did not work with isotopes. It indicates, despite the good results, the superiority of the conventional technique.

The replacement of the conventional radiography by computed radiography in weld inspection is perfectly feasible, although the new technique still needs improvements. Due to the lack of experience in the country and worldwide, the replacement process should be conducted cautiously.

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