APPLUS+ RTD RAYSCAN QUALIFICATION

Applus+ RTD RAYSCAN RTR Qualification for Pipeline Girth Weld Inspection

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Applicable contract(s) governing the provision of this Report:

Objective:

Applus+ RTD has undergone a qualification with DNV GL for their RTD RAYSCAN real-time radiography (RTR) system for inspection of pipeline girth welds, following the requirements of DNVGL-ST-F101 The trial welds for reliability tests included in total 11 girth welds of different diameters, wall thicknesses and material configurations. The qualified configurations are representative for a range of wall thicknesses between 2 mm to 25 mm, for pipes of diameter of 2" to 36", for both carbon steel and CRA applications and for full weld and partial weld inspection. DNV GL has witnessed the trials, and the qualification has been implemented according to the requirements set forth in the applied code and guideline.

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1 EXECUTIVE SUMMARY

Applus+ RTD has undergone a qualification with DNV GL for their RTD RAYSCAN real-time radiography (RTR) system for inspection of pipeline girth welds, following the requirements of DNVGL-ST-F101 [1]. The background for the qualification is the need for independent evaluation and endorsement of compliance with DNVGL-ST-F101 [1] requirements of the RTD RAYSCAN RTR system for the main application of pipeline girth weld inspection. The main benefits of the RTD RAYSCAN system compared with conventional radiographic testing are: No consumables, reduced exposure times, improved safety due to shielded systems and instant inspection results. RTD RAYSCAN uses the double wall single image technique (DWSI) to provide X-ray inspection of pipeline girth welds in real time. The qualification has included trials to document performance in sizing, positioning, characterization and detection, trial to document repeatability, and review of documentation. In total 11 trial welds were inspected as a part of the qualification trials by RTD RAYSCAN RTR and conventional reference RT according to standard requirements, resulting in validity of this qualification for the following pipeline girth weld configurations:

Table 1-1: Range of validity, RTD RAYSCAN RTR qualification

Parameter	Range of Validity
Diameter	2” to 36”
Wall thickness	5.0 mm to 25.0 mm
Materials	Carbon steel, CRA (iron and nickel based), Cladded and lined pipes
Extent	Full and partial weld

It is documented that RTD RAYSCAN RTR performs inspection in accordance with ISO 17636-2 [2] class B and DNVGL-ST-F101 [1] requirements using X-ray double wall single image (DWSI) technique. Based on the present qualification in accordance with DNVGL-ST-F101 Appendix D, Section F [1] requirements, RTD RAYSCAN RTR can replace standard conventional film based RT for the application of pipeline girth weld inspection. In summary, the following has been concluded on:

- Consistent and stable levels of SNR_N were confirmed upon repeated scans of the same weld. It is concluded that RTD RAYSCAN RTR is stable and provides consistent results upon repeated inspections.
- No indications detected by reference conventional RT were missed by RTD RAYSCAN RTR. Due to this, it is concluded that it has been documented that RTD RAYSCAN RTR performs with a minimum 90% POD at a 95% confidence level for critical imperfections according to DNVGL-ST-F101 requirements for film based radiography.
- Indication lengths are in general sized within ±5 mm with RTD RAYSCAN RTR compared with standard conventional RT.
- Difference in positioning of indication starting point in circumferential direction between RTD RAYSCAN RTR and conventional RT was confirmed in general to be within ±10 mm.

DNV GL has reviewed historical data, in which the circumferential accuracy of the RTD RAYSCAN RTR system has been reported to be within a range of ±3.5mm.

The RTD RAYSCAN RTR system applied upon pipeline applications with the DWSI technique is confirmed to perform better than the conventional RT DWSI technique using C3 system class films (ie. AGFA D4) and similar to the conventional RT SWSI panoramic technique using C5 system class films (ie. AGFA D7).

It is furthermore confirmed that the geometrical unsharpness of RTD RAYSCAN RTR DWSI is similar to the panoramic SWSI technique. The RTD RAYSCAN procedure is therefore regarded to be according to DNV-OS-F101 requirements when inspection is performed with a 50% reduction in source-to-object distance, provided that the IQI requirements are met, further reference is to document TD-16 003 [3].

On the basis of this General DNV-GL Qualification status of RTD RAYSCAN RTR, for project validation or verification purposes a technique shot is recommended meeting the minimum requirements as outlined in DNV-OS-F101 [1] and ISO 17636-2 Class B [2]. It can be noted that compliance according to DNVGL-ST-F101 ensures compliance with all previous revisions of DNV-OS-F101 which includes requirements to AUT, i.e. the 2000, 2007, 2010, 2012 and 2013 editions.

2 INTRODUCTION

Applus+ RTD has undergone a qualification with DNV GL for their RTD RAYSCAN real-time radiography (RTR) system for inspection of pipeline girth welds, following the requirements of DNVGL-ST-F101 [1] which is based on ISO 17636-2 [2] class B. This document reports the scope and results for this qualification work. The background for the qualification is the need for independent evaluation and documentation of compliance with DNVGL-ST-F101 requirements of the RTD RAYSCAN RTR system for the main application of pipeline girth weld inspection. The qualification covers both carbon steel and CRA materials, and both partial and full weld inspection.

The RTD RAYSCAN system is a real-time digital radiographic system designed to replace conventional film-based RT inspection for the application of pipeline and storage tank welds. The main benefits of the system are considered to be: Reduced exposure times, instant results, no consumables, improved safety due to shielded systems and no exposure to chemicals.

The RTD RAYSCAN RTR system was operated according to the Applus+ RTD general procedure for digital radiographic testing PIPL-06.05.0001 [4]. RTD RAYSCAN uses the double wall single image technique (DWSI) to provide X-ray inspection of pipeline girth welds in real time. This report can serve as documentation that the RTD RAYSCAN procedure is capable of performing according to DNVGL-ST-F101[1] requirements.

3 BASIS FOR WORK

The basis for this qualification work has been: DNVGL-ST-F101 [1], Appendix D. The main reference to digital radiography in this standard is to ISO 17636-2 [2]. Furthermore, requirements for automated NDT systems in section F of DNVGL-ST-F101 [1] and guidelines for replacement of NDE techniques in Nordtest Techn. Report No. 300 [5] has been followed. This is based on the consideration that the real-time radiographic (RTR) system is an automated system replacing conventional, manual radiographic testing (RT) for the pipeline girth weld inspection application.

4 OBJECTIVE

The main objective of the validation work has been to document that the Applus+ RTD RAYSCAN RTR procedure [4] complies with DNVGL-ST-F101, Appendix D, Section F [1] requirements. The qualification program has been focused on documenting equal or better performance of RTD RAYSCAN than corresponding conventional film based radiographic testing (RT). Formal requirements to digital radiographs provided in ISO 17636-2 [2] shall be demonstrated fulfilled for each radiograph. Furthermore, applicability on a wide range of applications was documented within the program.

According to DNV-OS-F101, Appendix D section F the basic requirements to qualification are:

- Document equivalence between RTR and conventional RT with regards to ability in detection, sizing and performance (ref. paragraph F102). This will often require practical tests (ref. paragraph F501).
- Review of documentation of function and operation of the RTD RAYSCAN system (ref. sub-section F200).
- Documentation of performance, in terms of accuracy in length sizing, positioning, characterisation, repeatability and detection compared with RT (ref. paragraph F301). This might

be done through practical trials, based on identification and evaluation of significant parameters and their variability (ref. paragraph F401).

5 ABBREVIATIONS

CRA – Corrosion Resistant Alloy

DWSI – Double Wall Single Image

IQI – Image Quality Indicator

POD – Probability of Detection

RT – Radiographic Testing

RTR – Real Time Radiography

SNR_N – Normalised Signal-To-Noise

SOD – Source to Object Distance

SR_b – Basic Spatial Resolution

SWSI – Single Wall Single Image

WT – Wall Thickness

6 DESCRIPTION OF QUALIFICATION PROCESS

6.1 Applus+ RTD RAYSCAN System Setup

6.1.1 RTD RAYSCAN RTR procedure

The RTD RAYSCAN RTR system has been qualified and operated according a general procedure, with document number PIPL-06.05.0001 [4].

The RTD RAYSCAN system consists of a series of scanners built for pipeline and storage tank girth weld inspection applications. The inspection principle is based on fully automated real-time capture of X-ray radiographs by a digital detector. The scanner designs allow efficient inspection and integrated radiation shielding allow good control of the safety aspects of radiographic testing.

Applus+ RTD has 6 designs of the scanner to fit the full range of pipe diameters from 2” up to 36”. These are summarised in Table 6-1.

Table 6-1: RTD RAYSCAN Scanner type overview

Scanner	OD Range	Shielded	X-ray Tube
Smallbore	2" to 12"	Yes	225kV
Oyster ST	8" to 24"	No	225kV/320kV
Oyster ST Shielded	8" to 22"	Yes	320kV
Oyster XL	24" to 36"	No	320 kV
Oyster XL Shielded	24" to 34"	Yes	320kV
Tie-in Scanner	≥6" (Portable)	No	225 kV

All scanners are working according to the same principle, and therefore also perform similarly. Operation can be either with single wall single image (SWSI) or double wall single image (DWSI) techniques. With SWSI, the X-ray source needs to be positioned at the pipe center inside the pipe using a crawler or for tank inspection on the other side of the wall. The scanner will capture the radiograph while the digital detector is moved at a fixed radial distance to the source around the full pipe/weld circumference. With DWSI, both the X-ray source and the digital detector are positioned outside the pipe, at the opposite side of the pipe to each other. Their relative position is locked, and upon scanning both the source and the detector will move around the pipe/weld circumference. For the present qualification trials, only the DWSI technique has been investigated. The version of the digital detector used during the trials (mk2) has a width of 12 mm wide across the scan direction.

Calibration and setup of the RTD RAYSCAN equipment shall follow the calibration procedure PIPL-12.03.0007 [6]. This procedure includes guidelines on how to determine the optimal kV/mA parameters according to the dynamic range (or gray scale levels) of the detector for the specific pipe/weld configuration to be inspected. The scan speed will be set to allow the standard requirement for normalised signal-to-noise level (SNR_N) (i.e. 140 for class B, measured in the parent material) is consistently fulfilled upon scanning. For the most heavy wall thicknesses in the trials, a scan speed of about 3 mm/sec was maintained.

6.2 Qualification requirements and approach

The trials within the qualification program were agreed in order to document compliance with DNVGL-ST-F101 [1] requirements. The requirements considered as relevant for an automated real-time radiographic system are described below.

The requirements that provides the basis for performing the qualification activities are provided in DNVGL-ST-F101 Appendix D, section F [1] for automated NDT systems, and replacement of manual inspection with an automated procedure. When an automated NDT system is introduced to replace an established and/or standard inspection procedure, qualification activities have to be performed in order to document equivalence with regards to function, operation and ability in detection, sizing and performance. The RTD RAYSCAN RTR system is considered as an automated NDT system which will replace standard conventional film-based radiographic testing for pipeline girth weld inspection. According to the requirements of DNVGL-ST-F101 Appendix D, section F [1], the following activities have to be performed as a part of a qualification:

- Review of documentation and historical data

- Documentation of performance, including accuracy in sizing and positioning, imperfection characterisation, repeatability and detection
- Evaluation of provided documentation and performance data

The basic requirement for radiographic testing according to DNVGL-ST-F101 [1] is that testing shall be performed in accordance with ISO 17636 class B. For a digital system, ISO 17636-2 [2] is the applicable part. The following essential parameters were closely evaluated within the qualification:

Table 6-2: Essential variables for digital RT, ISO 17636-2 [2]

Parameter	Requirement
Source-to-object distance:	Formal requirements to minimum source-to-object distance (SOD) to be complied with, determined by position of source, focal spot size and object to detector distance.
Dead pixel map	Requirement to document dead pixel map
Sensitivity	Contrast sensitivity to be documented using single wire IQI, depending on pipe wall thickness.
Spatial Resolution	Basic spatial resolution (SR_b) to be documented using duplex wire IQI, depending on pipe wall thickness.
Noise level	Normalised Signal-to-Noise ratio (SNR_N) to exceed minimum values, depending on X-ray tube voltage.

Differences between conventional film based RT and RTD RAYSCAN RTR were identified upon the initial documentation review, and provided the basis for the agreed qualification activities. While the same inspection technique can be applied with both film based RT and with RTD RAYSCAN RTR, the essential differences are considered to be the recording media (film vs digital detector) and the more rigid conditions for setup parameters with a scanner compared with the more flexible films. A set of practical qualification activities which addressed these considerations were agreed. These are specified in a RTR qualification program document [7], and briefly summarised in Table 6-3.

Table 6-3: Trials of the RTD RAYSCAN RTR qualification

Trial	Content	Trial outcome
Comparison, RTD RAYSCAN RTR DWSI and conventional RT DWSI	Testing of 9 trial welds with both techniques	Direct comparison in performance, in terms of accuracy in sizing and positioning, imperfection characterisation, repeatability and detection, see chapter 6.6
Comparison RTD RAYSCAN DWSI and Conventional RT SWSI	Testing of 2 trial welds with both techniques	Direct comparison in detection performance.
Scan trials of welds with OD range 2” to 36”	Testing of 9 trial welds	Document equivalent compliance with standard requirement of small bore, medium bore and large bore RTD RAYSCAN scanners. All inspection shall comply with ISO 17636-2 requirements.
Repeatability trials	5 repeated scans of 1 trial weld	Document stability upon repeated scans, see chapter 6.6.2.
Source to object deviation	1 scan of 1 trial weld	Trial to qualify deviation to ISO 17636-2 requirement on source-to-object distance due to different conditions for geometric unsharpness, see chapter 6.2.1

6.2.1 Source to Object Distance Deviation to Standard

One trial was perfomed in order to verify that the RTD RAYSCAN RTR system is not affected by the effect of increased geometric unsharpness towards the outer ends of the useful film/detector length, as is the case with conventional film-based RT (DWSI technique). The trial included one scan of the 9.6” OD full weld trial weld with 3 single wire IQI’s positioned at the source side at 3 different locations.

One particularity with the RTD RAYSCAN RTR compared with conventional film radiography when performing DWSI technique radiography is the small detector size. The width of the applied mk2 detector for the trials is 12 mm. Using a conventional film, geometrical unsharpness is introduced in the image when the object-film distance varies between the central part and the peripheric parts of the film. The narrow digital detector works as an aperture which only captures the central part of the x-ray beam, and thereby ensures that the full radiograph is captured with the same object-film distance. No geometrical unsharpness will therefore be introduced due to varying object-film distance in the RTD RAYSCAN radiographs.

Applus+ RTD has requested a permanent technical deviation to the requirement with regards to source-to-Object Distance (SOD) for class B, reference is made to DNV-OS-F101, Appendix D. Further applicable reference is made to ISO 17636-2, section 7.6 [2], which opens up for a reduction in source-to-object distance of 50% for SWSI panoramic technique provided that class B IQI requirements are fulfilled. It is requested to allow for a similar relaxation for the RTD RAYSCAN DWSI RTR procedure, since the use of small size detector provides the same geometrical unsharpness as a SWSI panoramic would do.

6.2.2 Compensation Principle

ISO 17636-2 [2] allows for compensation if the requirements to spatial resolution SR_b cannot be met, i.e. if the class B requirements for image unsharpness by assessement of duplex wire IQI are not met. It is allowed to compensate for one missing resolved duplex wire by additional single wire IQI sensitivity of one wire, for up to two wires (compensation principle II). The principle is mentioned here since the spatial resolution of the digital detector is fixed by design, due to this it was paid attention to this during the trials.

RTD RAYSCAN RTR provides some magnification of the weld due to the necessary space between the detector and the weld. All the trials were performed with the mk2 RAYSCAN detector. It was confirmed during scanning that the spatial resolution was consistently equal to or better than the minimum requirements of ISO 17636-2 Class B. A minimum duplex wire IQI value of D11 was consistently confirmed for all scans, this is considered as the spatial resolution provided by the applied detector. This is sufficient to comply with the requirement for inspection including penetrated thicknesses from 8 mm and above.

6.3 Trial welds

Defective welds of various configurations used for evaluation of performance were prepared by Serimax. The scope included 11 girth welds of the configurations listed in the Table 6-4 below.

Table 6-4 Total number of defective welds in the qualification

OD	Nominal WT [mm]	Partial WT	Number	Bevel	Material
9.6″	17.9 mm+ 3.0 mm Clad	-	1	J5	DNV MWP 450 SFPD + CLC 2242 (Alloy 825)
9.6″	17.9 mm+ 3.0 mm Clad	7.0 – 8.0 mm	7	J5	DNV MWP 450 SFPD + CLC 2242 (Alloy 825)
2″	5.5 mm	-	1	V	Carbon steel
3″	7.8 mm	-	1	V	CRA (TP 304L)
36″	18.0 mm	-	1	V	Carbon steel

Intentionally induced imperfections were of both surface breaking and sub-surface types, spread over the full depth range with varying height and length, in order to ensure unpredictable weld condition for the interpreters. Intentionally induced imperfections were induced by manipulation of welding parameters and by careful machining to desired imperfection height, orientation and at desired depth along the weld bevel. Some embedded artificial imperfections were formed when machined voids were partly filled upon subsequent welding. Upon review of the macro sections, the artificial lack of fusion type of imperfections was in general found to be relevant with regard to position, orientation and shape.

6.3.1 Inspection Parameters

The inspection parameters used for the trials are summarised in the Table 6-5 below.

Table 6-5: Inspection parameters, trials

OD	Nominal WT [mm]	Material	Voltage	Ampere	Focus spot size
9.6"	17.9 mm+ 3.0 mm Clad	DNV MWP 450 SFPD + CLC 2242 (Alloy 825)	320 kV	13 mA	5.5 mm
9.6"	17.9 mm+ 3.0 mm Clad (Partial)	DNV MWP 450 SFPD + CLC 2242 (Alloy 825)	290 kV	10 mA	5.5 mm
9.6"	17.9 mm+ 3.0 mm Clad (Partial, DWSI vs SWSI trial)	DNV MWP 450 SFPD + CLC 2242 (Alloy 825)	220 kV and 225 kV	11 mA and 13 mA	5.5 mm
2"	5.5 mm	Carbon steel	140 kV	3.0 mA	1.0 mm
3"	7.8 mm	CRA (TP 304L)	165 kV	3.6 mA	1.0 mm
36"	18.0 mm	Carbon steel	320 kV	13.0 mA	5.5 mm

6.4 Extent of Qualification Activities and DNV GL witnessing

The extent of qualification activities was agreed upon upfront. The trials are described in the qualification program documentation [7]. The following activities have been performed by Applus+ RTD, and witnessed by DNV GL:

- Review of documentation and historical data
- Verification of radiographic setup upfront all scanning for compliance with DNV-OS-F101 and ISO 17636-2 class B requirements, including test arrangement and dead pixel map
- Scanning of 9 test welds, both full weld and partially filled welds. It was verified that all scans were in accordance with formal requirements with regards to sensitivity, spatial resolution (SR_b) and signal-to-noise (SNR_N)
- Repeatability trials, 5 repeated scans of selected weld H-1318
- Trial for verification of source-to-object distance deviation.
- Analysis, including comparison between results from RTD RAYSCAN RTR and conventional RT

The following activity has been performed by Applus+ RTD and reviewed by DNV GL:

- Review of test reports and RTD RAYSCAN RTR scans of 2 partially filled welds
- Analysis, including comparison between results from RTD RAYSCAN RTR DWSI and conventional RT SWSI.

6.5 Reference testing

Reference testing by conventional radiographic testing (RT) technique was performed by Serimax and Applus+ RTD according to a standard procedure for radiographic testing of welds according to EN ISO 17636-1 Class "B" [8]. By conventional RT it is meant film based inspection by X-ray, performed in accordance with the clearly defined requirements of DNV-OS-F101. Techniques for conventional RT were selected for the different pipe and weld configurations in accordance with normal considerations for field inspection. The applied parameters are summarised in Table 6-6.

Table 6-6: Conventional RT setup for reference testing

OD	Nominal WT [mm]	Technique	Voltage	SOD	Current	Film System Class
9.6"	17.9 mm+ 3.0 mm Clad	DWSI	300 kV	350 mm	4.5 mA	C3
9.6"	17.9 mm+ 3.0 mm Clad (Partial)	DWSI	295 kV	400 mm	3.0 mA	C3
2"	5.5 mm	DWDI	210 kV	800 mm	4.5 mA	C3
3"	7.8 mm	DWDI	235 kV	900 mm	4.5 mA	C3
36"	18.0 mm	DWSI	300 kV	1200 mm	4.5 mA	C3
9.6"	17.9 mm+ 3.0 mm Clad (Partial)	SWSI	160 kV	124 mm	1.7 mA	C5

6.6 Analysis Extent

6.6.1 General Considerations

It has been witnessed and confirmed upon scanning that all results have been derived from inspection according to DNVGL-ST-F101 [1] and ISO 17636-2 [2] requirements. The criteria applied for inspection quality evaluation are all according to ISO 17636-2 [2] class B requirements, which are summarised in Table 6-2.

6.6.2 Repeatability

Repeatability trials were performed by running 5 consecutive scans of the same weld. Consistency in inspection performance was documented by consistent result of the standard image quality measures for the radiograph: Sensitivity, and normalised signal to noise ratio. In addition, it was confirmed that the spatial resolution was maintained through reading of duplex wire penetrameter.

The weld used for the trial was weld no. H-1318, which was full weld 9.6" OD x 17.9 mm + 3.0 mm Clad (CLC 2242). The weld was clean of significant indications, 2 insignificant single pore indications were reported from the weld.

Consistency in SNR_N level was evaluated by mean value (μ) ± 2 times standard deviation (σ), which corresponds to the interval where 95% of the observations are expected to fall within if a normal distribution is assumed. The normal distribution is considered as a reasonable assumption, as the level of noise in the captured radiograph is considered to be randomly distributed. Some variations in normalised signal to noise shall therefore be expected when sampled at various location on the weld and at the detector. A deviation within 10% of normalised signal to noise level was considered as a stable condition.

6.6.3 90% POD at 95% Confidence

The elementary detection criteria provided in Nordtest Technical Report N300 [5] has been applied to compare inspection performance for RTD RAYSCAN RTR with corresponding conventional RT. These criteria take basis in the probability of detection (POD) of both procedures or techniques that are compared as follows:

- The lower 95% confidence level of the POD value for the replacement NDE technique shall be equal to or higher than the average POD value for the reference technique minus 0.1
- The difference between the average value and the lower 95% confidence level of the POD value for the reference NDE technique shall be less than or equal to 0.1

The binomial distribution was selected for the evaluation of POD according to the criteria above due to the discrete nature of the outcome of the inspection. The distribution function b(x;n,p) and the cumulative binomial distribution B(x;n,p) can be expressed as:

$$b(x;n,p) = \binom{n}{x} p^x (1-p)^{n-x}$$

$$B(x;n,p) = P(X \leq x) = \sum_{i=0}^{x} \binom{n}{i} p^i (1-p)^{n-i}$$

, where there are i successful detections "hits" among n independent trials, and p is the probability of detecting a flaw. These detection criteria are usually attributed to a flaw dimension. In the case of the binomial distribution, all observations in the sample have in principle to stem from sub-critical flaw sizes if the aim is to conclude on POD for critical flaw sizes.

Using the binomial distribution, the detection of each flaw will be considered as a Bernoulli trial, with a fixed probability of 90% to detect a flaw to achieve the criterion of 90% POD. The 95% confidence level will be ensured for the lowest number of detections within a sample of observations where the accumulated probability exceeds 95%. The lowest number the criteria for 95% confidence level is fulfilled is 29 detections within a sample of 29 flaws. The criteria cannot be fulfilled for smaller samples than 29. Further to mention, if there are any non-detected flaws within the sample, the criteria might still be met if the sample size is increased to 46 or higher (45 detections out of 46 flaws).

This approach has been employed to compare inspection results from the same set of trials welds captured by RTD RAYSCAN RTR and conventional RT, in line with the approach described in Nordtest Technical Report N300 [5]. The conventional RT, performed according to standard requirement is the method that is replaced by the RTD RAYSCAN RTR method. Equal detection or better is considered documented when minimum 29 out of 29 indications reported by conventional RT is detected and reported by RTD RAYSCAN RTR.

6.7 Analysis Considerations

The main part of the trial welds in the qualification program are partial CRA welds. This was due to practical reasons. With regards to inspection performance, the difference between a full weld and a partial weld is considered to cause no difference provided that the thickness of the partial weld is monitored. Inspection sensitivity and standard requirement will be determined by the thickness of the material to be inspected in all cases.

The results from the conventional RT is used as the reference method during evaluation of the performance of the RTD RAYSCAN RTR procedure. This is motivated by the fact that the conventional RT is performed according to the standard requirements, and therefore represents the minimum level of quality the RTD RAYSCAN RTR procedure needs to perform at.

The parameters for reference conventional RT were selected to be comparable to the RTD RAYSCAN RTR procedure, and to be representative to the application of offshore pipeline girth weld inspection which the RTD RAYSCAN RTR procedure is intended to replace. Due to this, the analysis are mainly based on a direct comparison between results derived by RTD RAYSCAN RTR and conventional RT performed by DWSI method. In addition, the results of RTD RAYSCAN RTR were compared with the results of conventional RT panoramic SWSI for 2 welds, performed in line with the standard requirements for offshore pipeline girth weld field inspection [8]. This procedure normally includes use of a fast F6 film, to accommodate application requirements to inspection speed. For the present trials, comparable C5 system class films (eg. AGFA D7) were used. The welds used for this trial had numbers H1328 and H1454. It is emphasised that all conventional RT has been performed within DNV-OS-F101 requirements.

7 QUALIFICATION RESULTS

7.1 Compliance to Standard

Applus+ RTD demonstrated the test setup prior to each scan to be in compliance with their written procedure, DNVGL-ST-F101 [1] and ISO 17636-2 [2] class B requirements. The following was demonstrated upfront inspection with each new setup during the trials:

- Correct positioning of the scanner and alignment of the source and detector
- Correct placement of the IQIs
- Confirmed source to object distance
- Bad pixel map (captured and documented)
- Calibration of measurement scale

It was confirmed and documented that the bad pixel map complies with requirements of ISO 17636-2 [2].

After each scan, the following were confirmed for the recorded radiograph, to be in line with DNV-OS-F101 [1] requirements. All this information has been captured and submitted to DNV GL:

- Sensitivity (single wire IQI)
- Spatial resolution (SR_b, double wire IQI)
- Signal-to-noise ratio (SNR_N)

It should be noted that placement of the IQI directly on the detector surface as outlined in ISO 17636-2 Annex C is not feasible for in-motion scanning with the RAYSCAN system. Applus+ RTD had earlier performed a reference image measurement to determine the basic spatial resolution SR_b, according to ISO 17636-2:2013 requirements, as reported in technical note TN 16017[9]. The reference image of the RAYSCAN Mk2 detector gave an $SR_b^{detector}$ =80 μm, corresponding to D11 duplex wire IQI. For the qualification trials this result was confirmed through a radiograph with the duplex IQI placed as close as possible to the detector as specified for basic spatial resolution (SR_b) detector, rather than on source side as for SR_b image. Even though the duplex IQI is placed on the object, the SR_b measured is considered the mandatory $SR_b^{detector}$ measurement for these trials, not the optional SR_b^{image}.

7.2 Repeatability

The weld H-1318 was scanned 5 consecutive times, to document consistency in inspection performance. The results are documented in Table 7-1.

Table 7-1: Repeatability trial results, SNR consistency

		Normalised SNR at various positions, base material		
Scan	**Duplex IQI**	**SNR_N 1**	**SNR_N 2**	**SNR_N 3**
01	D11	191.7	181.9	171.4
02	D11	180.4	176.0	173.1
03	D11	188.7	184.0	174.9
04	D11	176.7	195.8	176.5
05	D11	177.9	190.5	173.2

Values for SNR_N is observed consistently within the range between 171.4 to 195.8. The observed mean value was 180.9, with a standard deviation σ of 7.74. All observations were within the range of the mean value ± 2σ, which corresponds to the interval where 95% of the observations are expected to fall within if a normal distribution is assumed. This interval corresponds further to SNR_N 180.9 ± 8.6%, which is considered as stable.

In addition to SNR, consistent spatial resolution (duplex wire IQI D11) and consistent sensitivity (single wire IQI W13) was confirmed for all scans.

7.3 Source to Object Distance Deviation to Standard

The required IQI sensitivity (W13) was confirmed similarly for all 3 positions along the weld circumference upon the verification scan. It was through this confirmed that the geometric unsharpness remains unchanged in the circumferential direction, and that the required detector side IQI sensitivity was achieved with source side positioned IQI's with RTD RAYSCAN RTR.

7.4 Comparison with Conventional RT

7.4.1 Comparison between RTD RAYSCAN DWSI and conventional RT DWSI

The comparison between reported weld imperfections by RTD RAYSCAN DWSI RTR and conventional DWSI RT in accordance with DNVGL-ST-F101 requirements [1] confirmed that RTD RAYSCAN RTR performs similar or exceeds the performance of comparable conventional RT. All of the weld imperfections reported by conventional RT by DWSI or DWDI techniques were reported by RTD RAYSCAN RTR. The number of reported weld imperfections are summarised in Table 7-2 below.

Table 7-2: Number of reported indications, RTR and conventional RT

Dia	Weld Configuration	Weld No.	RAYSCAN RTR	Conventional RT
9.6″	Clad, Partial weld	H1544	11	11
9.6″	Clad, Partial weld	H1545	11	8
9.6″	Clad, Partial weld	H1546	15	7
9.6″	Clad, Partial weld	H1547	8	2
9.6″	Clad, Partial weld	H1548	12	8
9.6″	Clad, Full weld	H1318	2	0
2″	Cs, Full weld	RTR-TR-001	3	3
3″	CRA, Full weld	RTR-TR-003	13	7
36″	Cs, Full weld	RTR-TR-010	2	0
Summary Total			**77**	**46**

The weld imperfections which are reported with RTD RAYSCAN RTR but not by conventional RT are observed to be mainly planar lack of fusion types for the partial welds and small sized scattered porosity for the full welds.

It is confirmed through detection of all weld imperfections reported by conventional RT that RTD RAYSCAN RTR has with a 95% confidence level at least the same probability of detection as comparable conventional RT in accordance with DNVGL-ST-F101 [1] requirements. This has been confirmed through fulfilment of the elementary detection criteria of Nordtest Technical report 300 [5], which is based on statistical considerations using the binomial distribution.

Characterisation of weld imperfections is observed to be identical in the RTD RAYSCAN RTR and conventional RT reports.

Difference in positioning of weld imperfections starting point in circumferential direction between RTD RAYSCAN RTR and conventional RT was confirmed in general to be within ±10 mm. A few observations of scattered porosity were observed to be positioned with larger difference in circumferential position, maximum 15 mm difference. In general, the inaccuracy is most likely caused by the conventional lead letter measuring tape. Additional deviations in positioning of porosity is considered to be due to the slight differences observed in the probability of detection, which might influence on detection of the weakest indications in the radiographs. The comparison includes 57 observations from the 5 clad partial welds 9.6″ OD configuration.

The differences in reported weld imperfection lengths between RTD RAYSCAN RTR and conventional RT is plotted in Figure 7-1. Difference in length sizing is in general observed within ±5 mm, with some larger deviations observed for porosity cluster type of indications. These observed differences are considered to be mainly due to operator dependency and not due to the capabilities of the inspection techniques used.

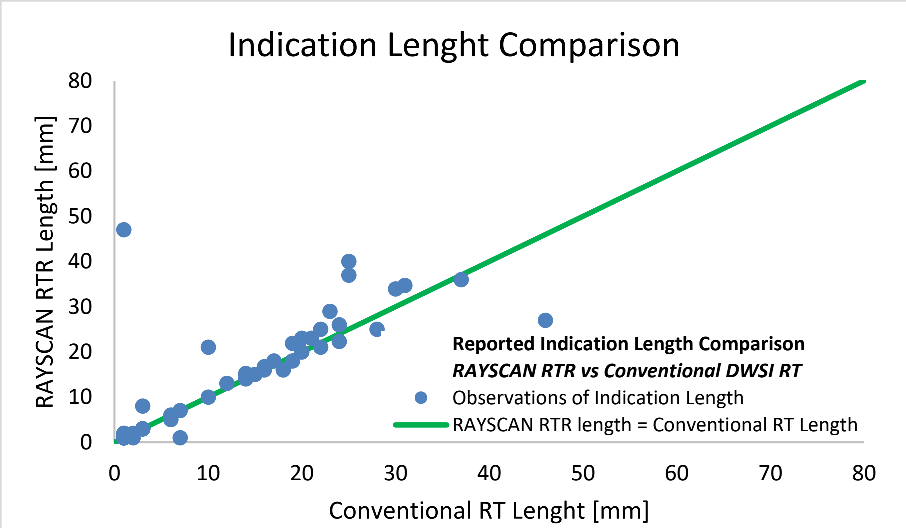

Figure 7-1: Comparison in indication length sizing between RTD RAYSCAN RTR and conventional RT. Outliers with differences more than ±5 mm are from observations of cluster porosity.

7.4.2 Comparison between RTD RAYSCAN DWSI and conventional RT SWSI

The comparison between reported weld imperfections by RTD RAYSCAN DWSI RTR and conventional SWSI RT in accordance with DNVGL-ST-F101 requirements [1] confirmed that RTD RAYSCAN RTR performs similar to the performance of conventional RT as applied for offshore pipeline production applications using C5 system class film (i.e. AGFA D7). All of the weld imperfections in welds H1328 and H1454 reported by conventional RT by SWSI technique were reported by RTD RAYSCAN RTR.

7.5 Historical data

DNV GL made a review of historical data for RTD RAYSCAN RTR made available. Applus+ RTD has a considerable track record of use of their RTR procedure since 2010. It was confirmed that the RTD RAYSCAN RTR procedure has historically mainly been applied on wall thicknesses within the range included in the qualification trials.

The procedure has been under improvement since it was introduced. Notable recent improvements have been development of scanners that can inspect larger pipes (the Oyster scanner), and improved detector design (mk2). It was confirmed during the review that all implemented changes in the procedure over the years have provided improvements to the inspection performance.

Heat trials up to 200 °C has been performed during one of the projects within the historical data. The experiences from this trial indicated that the detectors applied in the RTD RAYSCAN RTR setup can operate at elevated temperatures >140 °C, which was the temperature the IQI’s started to melt. This trial was not repeated under the present qualification, as it was considered not relevant in general for the intended use of RTD RAYSCAN RTR. It can be noted that the semi-conductor based detectors used with the RTR system are considered to be sensitive to elevated heat. However, stable conditions for detection is ensured by permanent cooling and close temperature control by peltier elements in the detector.

Historical trial results for linearity, to establish circumferential accuracy in positioning were reviewed. Trials included 6 pipe specimens with OD varying from 6” to 10”, all with 8 flat-bottom holes machined equally spaced over the circumference, and all scanned by the RTD RAYSCAN RTR system. The physical distances between the flat-bottom holes were compared with the distances as measured on the digital radiograph. The circumferential accuracy of the system was reported to be within a range of ±3.5mm. This is well within 1% of the length of the pipe circumferential for all pipes included in the trial.

8 CONCLUSIONS

8.1 Compliance to Standard

It is documented that RTD RAYSCAN RTR performs inspection in accordance with ISO 17636-2 class B [2] and DNVGL-ST-F101 [1] requirements using X-ray double wall single image (DWSI) technique. Based on the present qualification in accordance with DNVGL-ST-F101 Appendix D, Section F [1] requirements, RTD RAYSCAN RTR it is concluded that can replace standard conventional film based RT for the application of pipeline girth weld inspection. Validity is for the following pipeline girth weld configurations, or others if demonstrated to perform in line with the qualified performance:

Table 8-1: Range of validity, RTD RAYSCAN RTR qualification

Parameter	Range of Validity
Diameter	2” to 36”
Wall thickness	5.0 mm to 25.0 mm
Materials	Carbon steel, CRA (iron and nickel based), Cladded and lined pipes
Extent	Full and partial weld

It is recommended to document validity for on specific material for project use. As a minimum, validation can be sorted out as a Technique Shot. A Technique Shot is the inspection of a reference weld that matches the exact specification of the welds within the scope of the project, and shall demonstrate code compliance with regards to sensitivity, SNR_N and SR_B. All inspection parameters of the Technique Shot shall match the parameters of the production weld inspections.

Compliance according to DNVGL-ST-F101 ensures compliance with all previous revisions of DNV-OS-F101 which includes requirements to AUT, i.e. the 2000, 2007, 2010, 2012 and 2013 editions.

8.2 Performance data

8.2.1 Repeatability

Consistent and stable levels of SNR_N were confirmed upon repeated scans of the same weld. In addition the same sensitivity was confirmed in all scans. It is concluded that RTD RAYSCAN RTR is stable and provides consistent results upon repeated inspections.

8.2.2 Detection Capability

It was confirmed that 46 indications detected and reported through reference inspection by conventional RT according to DNVGL-ST-F101 requirements were all detected and reported with RTD RAYSCAN RTR. No indications detected by reference conventional RT were missed by RTD RAYSCAN RTR. Due to this, it is concluded that it has been documented that RTD RAYSCAN RTR performs with a minimum 90% POD at a 95% confidence level for critical imperfections according to DNVGL-ST-F101 requirements for film based radiography. This conclusion is based on the direct comparison between RTR results and the results with standard conventional RT.

It was confirmed similar detection performance between RTD RAYSCAN RTR DWSI inspection and corresponding conventional RT SWSI (panoramic) inspection representative to offshore field applications using C5 system class film (i.e. Agfa D7).

8.2.3 Sizing Accuracy

Indication lengths are in general sized within ±5 mm. A few observations of larger deviations are observed for porosity cluster type of indications.

8.2.4 Positioning accuracy

Difference in positioning of indication starting point in circumferential direction between RTD RAYSCAN RTR and conventional RT was confirmed in general to be within ±10 mm. A few observations of scattered porosity were observed to be positioned with larger difference in circumferential position, maximum 15 mm difference.

The circumferential accuracy of the system has been reported to be within a range of ±3.5mm from historical data.

8.3 Source to Object Distance Deviation to Standard

It is confirmed that the geometrical unsharpness of the RTD RAYSCAN RTR DWSI is similar to that of the panoramic SWSI technique. The RTD RAYSCAN procedure is therefore regarded to be according to DNV-OS-F101 requirements when inspection is performed with a 50% reduction in source-to-object distance, provided that the class B IQI requirements are met. Further reference is made to document TD-16 003 [3].

9 REFERENCES

/1/ DNVGL Standard DNVGL-ST-F101: Submarine Pipeline Systems, edition October 2017

/2/ Non-destructive testing of welds Radiographic testing Part 2: X- and gamma-ray techniques with digital detectors, ISO 17636-2:2013

/3/ Deviation for Source to Object Distance using the RTD RAYSCAN System, TD-16 003

/4/ General Procedure for Digital Radiographic Testing, No. PIPL-06.05.0001

/5/ Guidelines for replacing NDE techniques with one another, Nordtest technical report 300, 1995-10

/6/ Control Procedure Calibration of Rayscan Equipment, PIPL-12.03.0007

/7/ Real-Time Radiography (RTR) Qualification Program, RT-16.487

/8/ Radiographic Examination Procedure, Doc. Ref. RT 21013

/9/ Technical Note RTD Rayscan Mk2 Detector reference Image Measurement