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HEALTH & SAFETY LABORATORY

Technical Assessment of Petroleum Road Fuel Tankers
Work Package 1 - Full scale testing and associated modelling
ASSESSMENT AND SUPPLY OF TANKERS

ES/14/39/07rev07

Report Approved for Issue By:	**Nigel Corlett, BEng(Hons), MSc, PhD, ACSM**
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HSL Project Number:	**PE05832**

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Technical Assessment of Petroleum Road Fuel Tankers

Disclaimer
Certain aspects of this report, and any results and conclusions set out within it, may be disputed by the tank manufacturer.

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EXECUTIVE SUMMARY

Background

Following examination, certain petroleum road fuel tankers have been found to not be fully compliant with the provisions of Chapter 6.8 of the European Agreement on the Carriage of Dangerous Goods by Road (ADR). Amongst other things, these tankers are seen to exhibit extensive lack-of-fusion defects in the circumferential weld seams which, based on a leak-before-break assessment[1], could rupture under rollover and ADR load conditions.

The Department for Transport (DfT) commissioned research consisting of three work packages (WPs):

- WP1 – Full scale testing and associated modelling; Health and Safety Laboratory (HSL).
- WP2 – Detailed Fracture and Fatigue Engineering Critical Assessment (ECA); TWI Ltd.
- WP3 – Accident data and regulatory implications, and production of an overall summary report of the research; TRL Ltd.

HSL has taken forward the tasks set out in WP1 to:

1. Develop an independent non-proprietary structural hydrodynamic model of GRW tankers, validate this model against the results of tanker tests, and report modelling findings, including the potential for tanker structural performance tests.
2. Design, construct and commission a test rig for tests of tankers, including selecting and procuring suitable instrumentation for data gathering.
3. Determine suitability of tankers for large scale tests and acquire tankers, as appropriate, in accordance with project objectives as specified by DfT.
4. Undertake tests on tankers, including preparing the tankers, assessing the tanker test method and results, and reporting the findings.
5. Capture collision and/or deformation data from relevant impacts, for example by laser scanning, to corroborate modelling and tanker tests, and reconcile any inconsistencies.
6. Engage in peer review activities on the overall DfT research programme.

This report describes work undertaken to deliver tasks 3 and 5.

Objectives

The objectives of tasks 3 and 5 were:

- Facilitate, as required by DfT, the inspection, examination, selection and procurement of tankers to be used by HSL and other consortium members in the delivery of the project, namely:
  - Radiography of a range of 8- and 10-banded GRW tankers of varying age considered during the inspection, examination and selection processes.
  - Procurement of a representative proof of concept tanker and best and worst case GRW tankers for topple test at HSL for WP1, selected from the range of GRW tankers radiographed, based on the extent of imperfections observed in the radiography of the tankers' circumferential welds.
  - Fatigue data collection on GRW tankers conducted by TWI within WP2.
- Capture data, including physical samples if needed, from damaged tankers where these data or samples may be useful in the research, namely:
  - Provision of metrology and/or physical samples for use in the research; for example for use in WP1 extension of HSL Finite Element (FE) models beyond the topple test

[1] *'Short-term Fitness for Service Assessment of [non-compliant] Road Tankers, TWI (Draft) Report 23437/1/13, September 2013 and 'Project 23437 Contract Amendment: Additional FEA for assessment of [non-compliant] road tankers, TWI (Draft) Report 23437/2/13, October 2013.*

conditions or for use in WP2 examinations of welds from toppled and accident-damaged tankers.

Main Findings

Twelve candidate 8- and 10-banded GRW tankers manufactured between 2007 and 2011 were radiographed. The radiography both informed the choice of tankers for tests and provided information on the condition of the circumferential welds for a sample of GRW tankers. Two 8-banded 6-compartment tankers, J2580 and J3910, were selected for topple tests. One 10-banded 6-compartment tanker, J3857, was selected for road tests to gather fatigue data within WP2.

GRW tankers between 2006 and 2012 can be characterised by two extrusion designs and changes in the welding processes for circumferential welds, as follows:
Period A (2006 – approximately middle 2008; jobs J1609 to J2606): Extrusion (between shell sections of tank) with integrated radial web, single sided dish (bulkhead/baffle) to extrusion weld, single wire semi-automated welding process and external tack welds applied during the manufacturing process (along the circumferential seam). J2580 is in this category.
Period B (middle 2008 to middle 2010; jobs J2711 to J3612): Extrusion excluding integrated radial web, double sided dish to extrusion fillet weld, single wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands.
Period C (middle 2010 to 2012; job J3733 onwards, including "FT" job numbers): Extrusion excluding integrated radial web, double sided dish-to-extrusion fillet weld, twin wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands. J3857 and J3910 are in this category.

Expert assessment by suitably qualified radiographers found indications of defects, primarily lack of fusion, which resulted in rejection of sections of the circumferential weld for all the GRW tankers radiographed. There was a wide variation, from 7.5 % to 60.1 % of the weld length radiographed being rejected for J2580 and J3910, respectively. These tankers were selected as the best and worst case GRW tankers for the topple test. GRW tanker J3857, selected for fatigue data collection, was at the lower end of rejection, having 13.8 % of the total length of weld radiographed rejected. The range and average for all GRW tankers radiographed was 7.5 % to 60.7 % and 37.4 %, respectively.

The GRW tankers selected for test were all fully ADR inspected and, where necessary, remedial work was undertaken to make the tankers ADR compliant, roadworthy and loadworthy. GRW tanker J3857 was inspected for roadworthiness and subjected to an MOT, subjected to ADR periodic inspection (with manway bolts and gaskets replaced and refitted), and certified gas-free before collecting on-road fatigue data. GRW tankers J2580 and J3910 were both subjected to ADR periodic inspection (with minor repairs to manway lids), removal of parts not needed for test, release of kingpin plate bolts, and gas-free certification for transport before delivery to HSL. After preparation for topple test at HSL, both tankers were subjected to a pressure test to the ADR periodic inspection requirements with pressure relief valves checked and adjusted, and manway bolts and gaskets replaced and refitted to ensure that the tankers were both fully sealed and loadworthy before topple test. In addition, the GRW tankers selected for topple test were radiographed a second time, which confirmed the lack of fusion indications already observed. These tankers were also subjected to internal surveys of their fillet welds. GRW tanker J3910 was also subject to an internal survey of circumferential weld misalignment and an external survey of circumferential weld caps using laser scanning techniques, the data from which was analysed within WP2.

A suitable 8-compartment 40,000 litre petroleum road tanker of aluminium construction in roadworthy and loadworthy condition was sourced for the proof of concept topple test.

Two accident-damaged GRW tankers, J3217 with rear damage, which was procured, and J3146 with front damage, have been laser scanned to provide dimensional information on the damage and physical samples have been taken for mechanical testing and post-mortem activities in WP2.

Physical samples for mechanical testing and post-mortem activities in WP2 were also taken from the topple tested GRW tankers; from the rear of the undamaged nearside and damaged off-side of J2580 and the front of the damaged off-side of GRW tanker J3910.

1 INTRODUCTION

This work has been conducted as part of the Department for Transport's (DfT) technical assessment of petroleum road fuel tankers.

Following examination, certain petroleum road fuel tankers have been found to not be fully compliant with the provisions of Chapter 6.8 of the European Agreement on the Carriage of Dangerous Goods by Road (ADR). Amongst other things, these tankers are seen to exhibit extensive lack-of-fusion defects in the circumferential weld seams which, based on a leak-before-break assessment[2], could rupture under rollover and ADR load conditions.

The Department for Transport (DfT) commissioned research consisting of three work packages (WPs):

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HSL has taken forward the tasks set out in WP1 to:

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2. Design, construct and commission a test rig for tests of tankers, including selecting and procuring suitable instrumentation for data gathering.
3. Determine suitability of tankers for large scale tests and acquire tankers, as appropriate, in accordance with project objectives as specified by DfT.
4. Undertake tests on tankers, including preparing the tankers, assessing the tanker test method and results, and reporting the findings.
5. Capture collision and/or deformation data from relevant impacts, for example by laser scanning, to corroborate modelling and tanker tests, and reconcile any inconsistencies.
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This report describes the work undertaken to meet the objectives of tasks 3 and 5:

- Facilitate, as required by DfT, the inspection, examination, selection and procurement of tankers to be used by HSL and other consortium members in the delivery of the project, namely:
  - Radiography of a range of 8- and 10-banded GRW tankers of varying age collected during the inspection, examination and selection processes.
  - Procurement of representative proof of concept tanker and best and worst case GRW tankers for topple test at HSL for WP1, selected from the range of GRW tankers radiographed, based on the extent of imperfections observed in the radiography of the tankers' circumferential welds
  - Fatigue data collection on GRW tankers conducted by TWI for WP2.
- Capture data, including physical samples if needed, from damaged tankers where these data or samples may be useful in the research, namely:
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[2] *'Short-term Fitness for Service Assessment of [non-compliant] Road Tankers, TWI (Draft) Report 23437/1/13, September 2013 and 'Project 23437 Contract Amendment: Additional FEA for assessment of [non-compliant] road tankers, TWI (Draft) Report 23437/2/13, October 2013.*

conditions or for use in WP2 examinations of welds from toppled and accident-damaged tankers.

The inspection and selection activities, excluding radiography, for GRW tankers J2580 and J3910, used for the topple tests, are described fully in the report on the topple tests (HSL ES/14/39/04 as given in Table 1) and are not reported in detail here.

Selecting undamaged tankers for different activities involved considerable overlap, so the processes and outcomes are described together in section 3. As selecting and sampling damaged tankers required different approaches, this is described separately in section 5.

The GRW tankers considered in this research were of "banded" construction - the tanker shell was constructed in short sections, and these were joined using an extrusion band between shell sections. Two circumferential welds joined each extrusion to two shell sections. Bulkheads and baffles were also welded to the extrusion band. In this report the term band is used to mean the constructed extrusion band, including the circumferential welds. The tanker used for the proof of concept test was of stuffed construction - the tanker shell was one single construction, and the bulkheads/baffles were fitted inside and welded to the inner wall of this shell.

This report is part of a package describing HSL's work on WP1. The reports in this package are given in Table 1.

Table 1 List of HSL reports in this report package for Work Package 1

ES/14/39/00	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Overall Summary
ES/14/39/07	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Assessment and Supply of Tankers **THIS REPORT**
ES/14/39/04	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Tanker Topple Test Methods and Results
ES/14/39/05	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Modelling to Provide Load Case Data for Rollover – Approach and Initial Development
ES/14/39/06	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Modelling to Provide Load Case Data for Rollover - Validation and Application

2 TANKERS CONSIDERED FOR THE RESEARCH

2.1 GRW TANKERS

DfT, with HSL support, compiled a list of candidate GRW tankers, based on discussions with, and visits to, tanker operators and tanker maintenance companies. GRW tankers from this list were selected for use in the research programme, as given in Table 2.

2.1.1 GRW tanker design and welding

Production of GRW tankers between 2006 and 2012 can be characterised by two extrusion designs and changes in the welding processes for circumferential welds. The configurations can be categorised as follows:

Period A (2006 – approximately middle 2008; jobs J1609 to J2606): Extrusion (between shell sections of tank) with integrated radial web, single sided dish (bulkhead/baffle) to extrusion weld, single wire semi-automated welding process and external tack welds applied during the manufacturing process (along the circumferential seam). J2580 is in this category.

Period B (middle 2008 to middle 2010; jobs J2711 to J3612): Extrusion excluding integrated radial web, double sided dish (bulkhead/baffle) to extrusion fillet weld, single wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds in most bands.

Period C (middle 2010 to 2012; job J3733 onwards, including "FT" job numbers): Extrusion excluding integrated radial web, double sided dish (bulkhead/baffle) to extrusion fillet weld, twin wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands. J3910 is in this category.

Table 2 GRW tankers considered for the research programme "Technical assessment of petroleum road fuel tankers"

GRW number	Weld type	Year of manufacture	Number of bands	Number of compartments	Research use
J2079	A	2007	10	6	Radiography
J2080	A	2007	10	6	Radiography
J2297	A	2007	10	6	Radiography
J2580	A	2008	8	6	Radiography WP1 Topple test
J2946	B	2008	8	1	Radiography
J3029	B	2009	8	6	Radiography
J3564	B	2009	10	6	Radiography
J3857	C	2010	10	6	Radiography WP2 road test
J3861	C	2010	10	6	Radiography
J3909	C	2011	8	6	Radiography
J3910	C	2011	8	6	Radiography WP1 Topple test
J4171	C	2011	10	6	Radiography
J3217	B	2010	10	1	Damage - rear Laser scan Physical samples for WP2
J3146	B	2009	10	6	Damage - front Laser scan Physical samples for WP2

2.2 GRW TANKER BASIC CONSTRUCTION

2.2.1 Compartment and band labelling

- Compartment numbers run from C1 at the front of the tanker.
- Bands are labelled from A at the front of the tanker. The number of bands is identified by /8 for an 8-banded tanker and /10 for a 10-banded tanker.
- Where a specific side of a band is referred to, the suffix + has been used to denote the side closer to the front, and the suffix – for the side closer to the rear of the tanker. For example, from inside compartment 4 of an 8-banded tanker, the welds at E/8- and F/8+ can be seen.
- If needed, (B) after the label denotes a baffle and (BH) denotes a bulkhead.
- The M-*n* labels for bands refer to the naming convention used by a contractor, and run from M-1 at the rear.

2.2.2 8-banded GRW tanker

The basic configuration of an 8-banded 6-compartment taker is given in Figure 1. This is based on the drawing of a GRW 44,500 litre six compartment Tridem tanker, drawing number 085-45-500-03 supplied to HSL. Only compartment C1 contains a baffle, at band B/8.

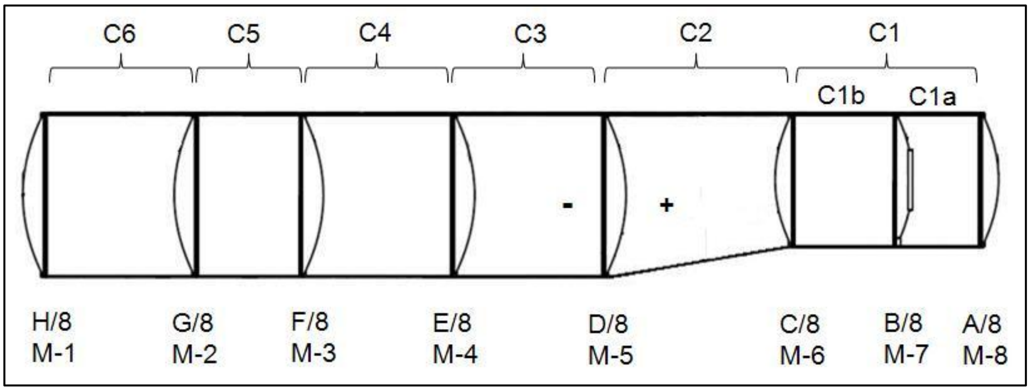

Figure 1 8-banded 6-compartment GRW tanker - bulkheads and baffles

2.2.3 10-banded GRW tanker

The basic configuration of a 10-banded 6-compartment taker is given in Figure 2. This is based on the drawing of a GRW 44,100 litre one compartment Tridem tanker, drawing number 085-44-500-05 supplied to HSL. Three compartments contain a baffle; band B/10 in C1, band D/10 in C2 and band G/10 in C4.

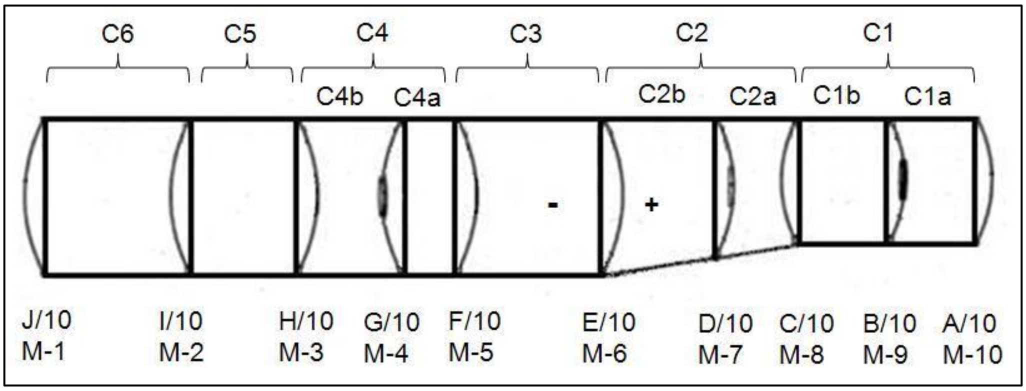

Figure 2 10-banded 6-compartment GRW tanker - bulkheads and baffles

2.2.4 Differences between 8- and 10-banded GRW tankers

These differences apply to the tankers considered and examined by HSL and may not be the same for all GRW tankers. The 10-banded tanker has a full baffle (D/10) approximately midway along compartment C2, the tapering compartment. In the 8-banded tanker, this has been replaced with an internal stiffener ring. Two vertical U section struts are bolted to this stiffener.
In compartment C4 of an 8-banded tanker, the baffle in the 10-banded tanker (G/10) has been replaced by a small stiffener along the bottom of the compartment. This stiffener runs across the bottom of the compartment between the locations of the longitudinal support beams.

2.2.5 Construction differences between GRW tankers J2580 and J3910

GRW tankers J2580 and J3910 (GRW weld periods A and C, respectively) were selected for topple test and, therefore, were subject to various inspections and surveys which provided information on the differences in construction between the tankers. These differences are described in detail in HSL reports ES/14/39/04 and ES/14/39/06, and are only summarised here. Appendix 1 lists the surveys conducted on GRW tankers J2580 and J3910.

Extrusion profile - GRW tanker J2580 was constructed using a different extrusion profile to that used in GRW tanker J3910.

Bulkhead/baffle welding - On GRW tanker J2580 the extrusion was only welded to the convex side of the bulkhead (or baffle), whereas on GRW tanker J3910 the extrusion was welded to both sides of the bulkhead (or baffle).

Fillet welds - The lengths and positions of the fillet welds with respect to the circumferential welds were different between GRW tankers J2580 and J3910.

2.2.6 Material properties of GRW tankers

Assessing the material properties for different GRW tankers is beyond the scope of HSL's work in WP1. However, as part of HSL's modelling work (HSL report ES/14/39/05), TWI supplied HSL with a series of test results on plate and weld metal from GRW tanker J3025.

2.3 OTHER TANKERS

In addition to the GRW tankers, one other tanker was considered for WP1. The proof of concept test for the topple test method (described in HSL report ES/14/39/04) did not necessarily require a GRW tanker; the requirement was for a readily available petroleum road tanker of aluminium construction in roadworthy and loadworthy condition. A tanker manufactured by Caldal S.L. in 1999 met these requirements and was sourced by HSL for the proof of concept test.

The proof of concept tanker was an 8-compartment 40,000 litre tanker of stuffed, rather than banded, construction. Close examination of the tanker revealed slight indications on the outside of the shell which were likely to correspond to bulkhead locations. The orientations of the bulkheads were inferred from the lengths of the compartments knowing that the volume of each compartment was similar; all compartments had a nominal capacity of 5000 litres. For example, the second compartment from the back was significantly shorter than the others, so to have the same volume, the bulkheads must face out at both sides. The likely internal configuration of the proof of concept tanker is given in Figure 3.

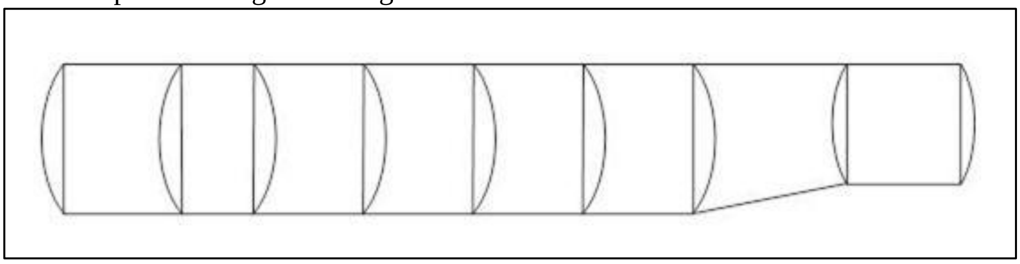

Figure 3 Likely internal configuration of the proof of concept tanker

3 SELECTION OF GRW TANKERS FOR TESTS AND RADIOGRAPHY

3.1 SELECTION CRITERIA

Radiography was conducted on the circumferential welds of a range of 8- and 10-banded GRW tankers of varying age. This provided the basis for selecting tankers for research activities, and provided information on the quality of the circumferential welds in different GRW tankers.

Best- and worst-case GRW tankers, based on the percentage of radiographed circumferential weld length rejected during expert assessment, were required to topple test at HSL for WP1. A GRW tanker with a low level of rejected weld length was required for the fatigue data collection conducted by TWI for WP2.

3.2 SELECTION ACTIVITIES

GRW tankers for tests **-** The sequence for activities that provided the information needed to choose a tanker for test work, with an indication of the decision points, was:

1. Identify GRW tanker and confirm potential price and availability
2. Confirm tanker MOT and roadworthiness and conduct preliminary assessment of ADR condition

decision point

   a. remedial work if needed

3. Transport tanker
4. Radiography of all circumferential welds
   a. DfT assess radiography

decision point

5. Transport tanker for inspection or return to owner
6. Full ADR inspection of tanker
   a. other loadworthiness inspection

decision point

   b. remedial work if needed

7. Transport tanker for further inspection or return to owner
8. Other (optional) pre-test inspections of tanker
   a. partial inspection corresponding to some aspects of full periodic ADR inspection
   b. second radiography of some or all circumferential welds
   c. pre-test survey of tanker, for example internal visual examination of welds
9. Optional pre-test work preparing tanker for test by third party
10. Transport tanker to test location

The exact order of actions, including decision points, varied between individual tankers and according to whether the activities were needed. Appendix 1 lists the inspections, assessments, surveys and work conducted on GRW tankers J2580, J3910 and J3857 which were selected and used for testing.

GRW tankers for radiography - The sequence for activities followed the same process, at least as far as step 5.

4 RADIOGRAPHY OF GRW TANKERS

Twelve GRW tankers were fully radiographed, covering all the bands. These tankers are listed in Table 2.

GRW tanker J2580 was partially radiographed a second time, and GRW tanker J3910 was fully radiographed a second time. Second radiography was conducted by a different contractor to the first.

All distances relating to radiographs are over the curved surface of the tanker.

4.1 RADIOGRAPHY METHODS

4.1.1 Contractor 1

Computed Radiography was conducted and assessed to EN ISO 10042: 2005 [1] Quality Level 'C'. The single wall, single image (SWSI) approach was used with the SWSI Source outside the tanker and the image plate (film) inside the tanker. Curvature of the bulkheads/baffles meant that the circumferential welds were only accessible (for placing the image plate) on the concave side of the baffle plates.

Radiographs were taken on both offside and nearside of the tankers, from the lowest accessible position on the band to the comb. Radiographs in the comb area were also taken for some tankers.

Bands were divided into shorter sections for the individual radiograph exposures which combined to form the overall radiography of the band. In general these sections were 35 cm long, with shorter lengths where necessary.

4.1.2 Contractor 2

Radiography was conducted and assessed to EN ISO 10042: 2005 [1] Quality Level 'C'. The SWSI approach was used, but with the SWSI Source inside the tanker and the image plate (film) outside the tanker.

Partial radiography of GRW tanker J2580 covered the offside only for three bands, F/8 (M-3), G/8 (M-2) and H/8 (M-1), from the lowest accessible position on the band to the comb.

GRW tanker J3910 was fully radiographed on both offside and nearside, from the lowest accessible position on the band to the comb.

Bands were divided into shorter sections for the individual radiograph exposures which combined to form the overall radiography of the band. In general these sections were 300 mm long, with shorter lengths where necessary.

4.2 STARTING POSITIONS OF RADIOGRAPHS ON THE TANKERS

The starting positions of radiographs on the tankers were similar for 8- and 10-banded GRW tankers with respect to the support ribs at the bands. HSL have only inspected 8-banded tankers closely.

Figure 4 illustrates the radiograph starting positions for the offside of 8-banded tankers; positions on the nearside and offside were similar. Radiographs of bands D/8 to H/8 (M-5 to M-1) started just above the top of the hose tray which runs along the tanker. The top of this hose tray is higher than the top of the support ribs which sit on the bands, as illustrated in Figure 5 which shows the nearside of GRW tanker J2580 before delivery to HSL. (The support ribs are shown above the top of the hose tray in Figure 4 to make their position clear.) Radiographs of bands A/8 to C/8 (M-8 to M-6) started above the support ribs which sit on the bands.

Further information on the starting positions of radiographs for GRW tankers J2580 and J3910 is given in Appendix 3.

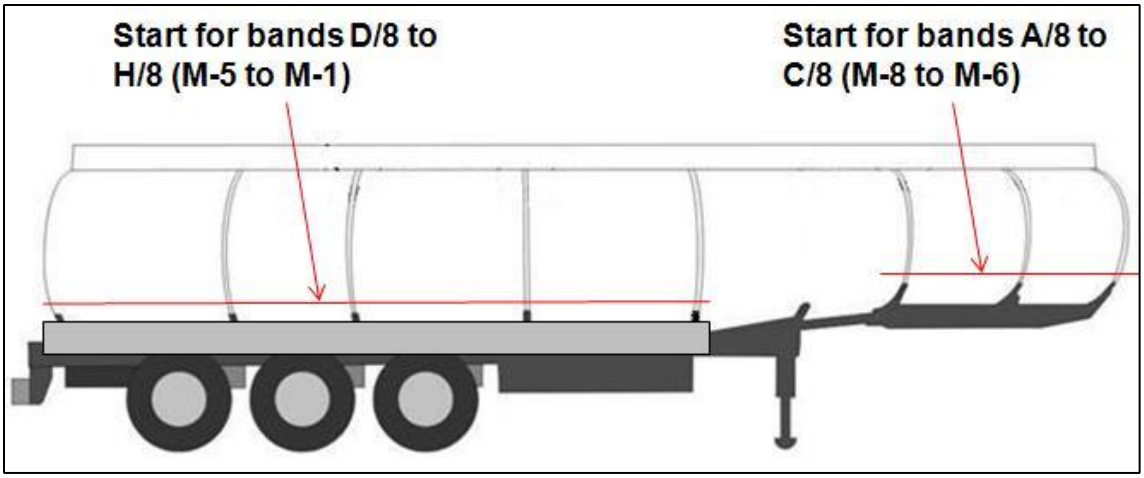

Figure 4 Schematic of radiograph starting positions for GRW 8-banded tanker

support ribs are shown above the top of the hose tray to make their position clear

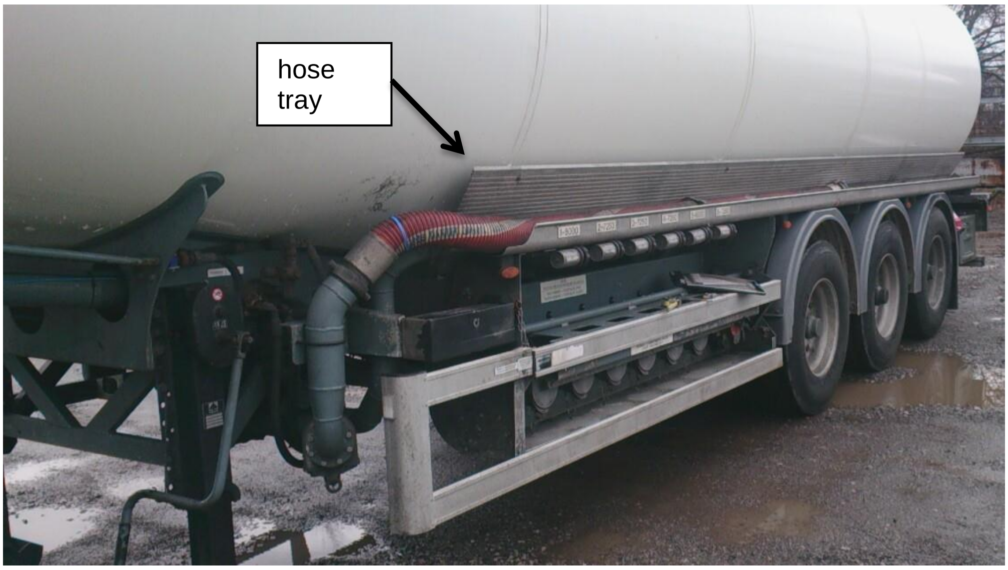

Figure 5 Nearside of GRW tanker J2580 with hose tray hiding support ribs

radiography of bands D/8 to H/8 started just above the top of the hose tray

For 10-banded GRW tankers, the starting positions for radiographs of bands E/10 to J/10 (M-6 to M-1) were just above the top of the hose tray which runs along the tanker. The starting positions for bands A/10 to D/10 (M-10 to M-7) were above the support ribs which sit on the bands.

4.3 RADIOGRAPHY REPORTS

4.3.1 Results reported

The radiography reports noted where the following features were found on the individual radiograph sections, and over what lengths:

- lack of fusion (LOF);
- intermittent lack of fusion;
- linear porosity;
- porosity;
- isolated pores;
- lack of penetration (LOP); and
- inclusions.

An overall acceptance or rejection for each individual radiograph section was given in the radiography reports, together with summaries of the number of defects and percentage length of defects in terms of total radiographed length in each band. Contractor 1 also provided photos of the tanker and the radiograph starting positions in the radiography reports.

4.3.2 Summary of radiograph results

Table 3 gives the overall percentage rejection, weld length radiographed and weld length rejected by contractor 1 for the circumferential welds of the GRW tankers from Table 2.

Table 3 Summary of GRW tanker radiograph results

GRW number	Year of manufacture	% rejected	weld length rejected mm	weld length radiographed mm
J2079	2007	49.1	18,970	38,610
J2080	2007	47.8	18,015	37,710
J2297	2007	60.7	24,750	40,750
J2580	2008	7.5	2,390	31,830
J2946	2008	28.5	9,330	32,740
J3029	2009	46.2	12,500	27,080
J3564	2009	27.8	12,220	44,020
J3857	2010	13.8	6,090	44,230
J3861	2010	34.7	16,030	46,260
J3909	2011	24.0	7,370	30,750
J3910	2011	60.1	18,400	30,650
J4171	2011	49.7	20,585	41,390
overall	-	37.4	167,940	448,780

A comparison between the radiography reports from the two contractors found that they were broadly similar, with both contractors reporting defects leading to rejection of radiograph sections caused by lack of fusion (intermittent and continuous) and lack of porosity. Contractor 1 also reported one example of elongated cavities, which led to rejection of a radiograph section. In addition, isolated pores and porosity were reported, but these did not lead to rejection of radiograph sections. Contractor 2 consistently reported higher levels of defects than contractor 1.

A summary of individual tanker radiography and a comparison between tankers is given in Appendix 2. More detailed acceptance and rejection information for GRW tankers J2580 and J3910 is given in Appendix 3.

5 DAMAGED GRW TANKERS

Metrology, including physical samples if needed, was required from topple tested and damaged tankers where these data or samples would be useful in the research. For example, for use in any WP1 extension of HSL finite element (FE) models beyond the topple test conditions or for use in WP2 examinations of welds from toppled and accident-damaged tankers.

Two damaged GRW tankers, J3217 and J3146, were identified and used to provided information for the research programme.

Samples from the topple tested GRW tankers J2580 and J3910 were taken and used by TWI in WP2 post-mortem studies.

5.1 DAMAGED TANKER J3217 - REAR IMPACT DAMAGE

GRW tanker J3217 was damaged at the rear offside by an impact from behind (Figure 6). It was laser scanned by HSL to provide dimensional information on the whole tanker, including the damage. Figure 7 is an image from the laser scan data. Physical samples of the damaged areas were taken for use in WP2.

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Figure 6 Damage to the rear of GRW tanker J3217

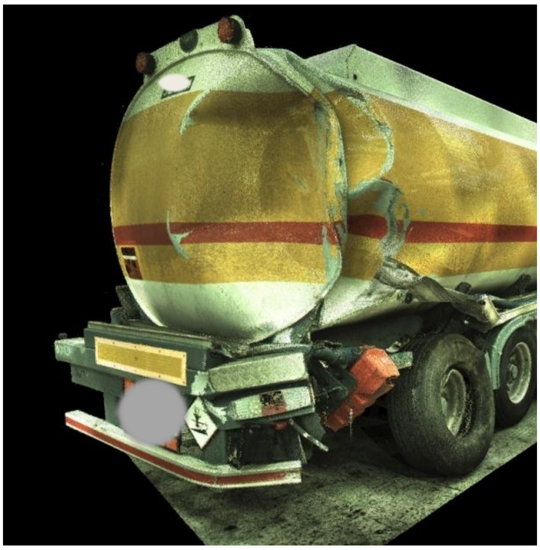


Figure 7 Laser scan image of the rear of GRW tanker J3217

5.2 DAMAGED TANKER J3146 - FRONT IMPACT DAMAGE

GRW tanker J3146 was damaged at the front offside corner, at band A/8, by an impact (Figure 8). While awaiting repair, GRW tanker J3146 was laser scanned by HSL to provide dimensional information on the whole tanker, including the damage. Figure 9 is an image from the laser scan data. Physical samples of the damaged areas were taken for use in WP2.

TWI images

Figure 8 Damage to the front of GRW tanker J3146

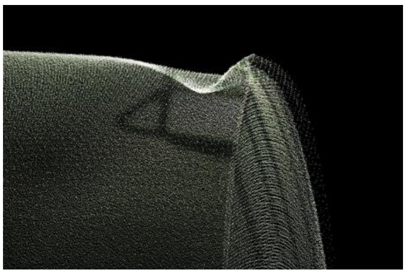
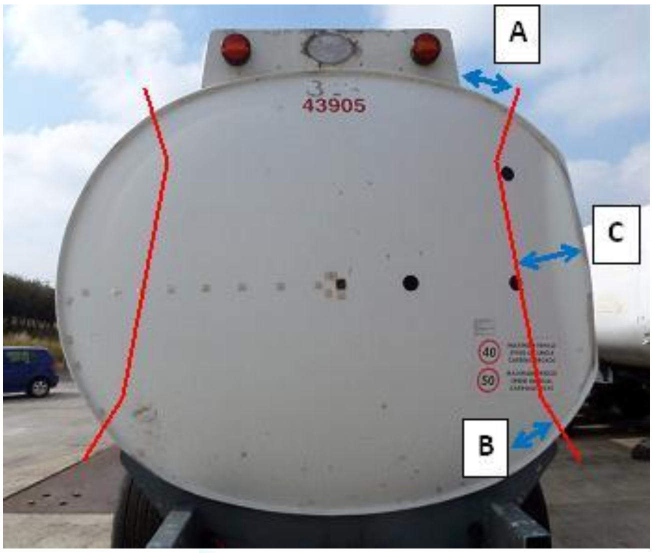


Figure 9 Laser scan image of the front damage on GRW tanker J3146

dark lines are shadows captured on scan

5.3 TOPPLE TESTED J2580 - REAR SAMPLES

GRW tanker J2580 was sampled at the rear on both the undamaged nearside and damaged off-side, as illustrated in Figure 10. The samples were used for testing mechanical testing and post-mortem activities in WP2.



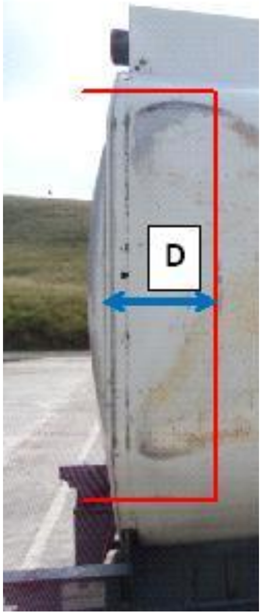


Figure 10 Samples from rear of J2580

end and side views

Rough dimensions - cuts on both sides similar

(Comb to impact top was about 600 mm.)

A - comb to cut 300-400 mm leaving at least 200 mm of metal before impact area

(Support rib to impact bottom about 380 mm.)

B - rib to cut 100-200 mm leaving at least 200 mm of metal before impact area

C - cut to be out of clearly deformed area of rear bulkhead - about 500 mm

D - at least 1.5 extrusion band widths from inner edge of band ie at least 200 mm from end of shell

5.4 TOPPLE TESTED J3910 - FRONT SAMPLE

GRW tanker J3910 was sampled at the front damaged off-side, as illustrated in Figure 11. The samples were used for testing mechanical testing and post-mortem activities in WP2.

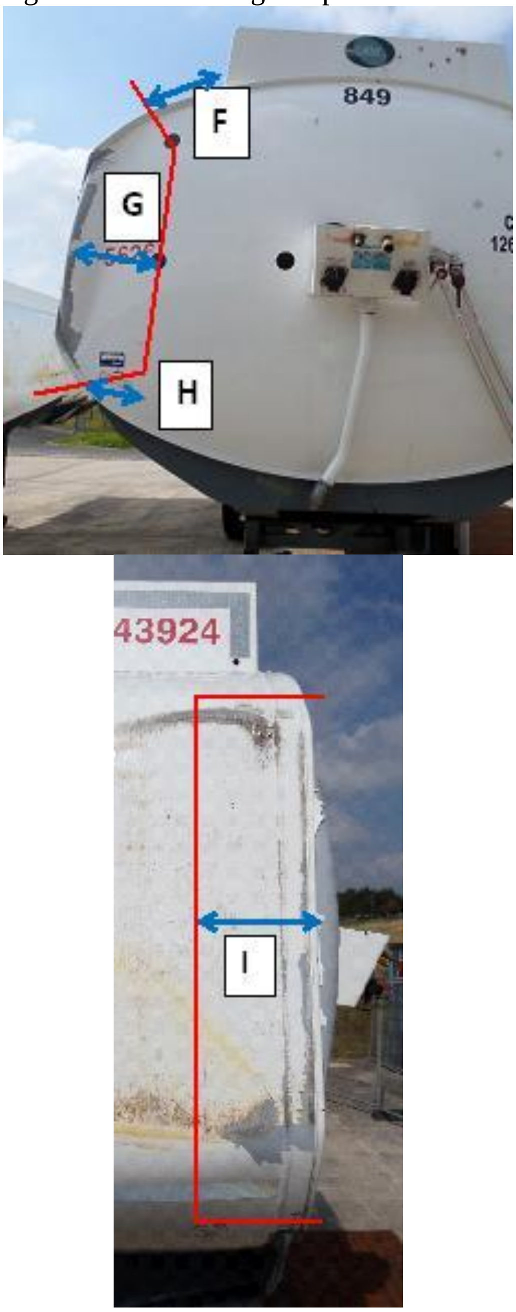


Figure 11 Sample from front of J3910

end and side views

Rough dimensions - cuts on both sides similar

(Comb to impact top about 650 mm.)

F - comb to cut 300-400 mm leaving at least 200 mm of metal before impact area

(Support rib to impact bottom about 280 mm.)

H - rib to cut 0-100 mm leaving at least 200 mm of metal before impact area

G - cut to be out of clearly deformed area of rear bulkhead - about 500 mm

I - at least 1.5 extrusion band widths from inner edge of band i.e. at least 200 mm from end of shell.

6 CONCLUSIONS

Twelve candidate 8- and 10-banded GRW tankers manufactured between 2007 and 2011 were radiographed. The radiography both informed the choice of tankers for tests and provided information on the condition of the circumferential welds for a sample of GRW tankers. Two 8-banded 6-compartment tankers, J2580 and J3910, were selected for topple tests. One 10-banded 6-compartment tanker, J3857, was selected for road tests to gather fatigue data within WP2.

GRW tankers between 2006 and 2012 can be characterised by two extrusion designs and changes in the welding processes for circumferential welds, as follows:
Period A (2006 – approximately middle 2008; jobs J1609 to J2606): Extrusion (between shell sections of tank) with integrated radial web, single sided dish (bulkhead/baffle) to extrusion weld, single wire semi-automated welding process and external tack welds applied during the manufacturing process (along the circumferential seam). J2580 is in this category.
Period B (middle 2008 to middle 2010; jobs J2711 to J3612): Extrusion excluding integrated radial web, double sided dish to extrusion fillet weld, single wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands.
Period C (middle 2010 to 2012; job J3733 onwards, including "FT" job numbers): Extrusion excluding integrated radial web, double sided dish-to-extrusion fillet weld, twin wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands. J3857 and J3910 are in this category.

Expert assessment by suitably qualified radiographers found indications of defects, primarily lack of fusion, which resulted in rejection of sections of the circumferential weld for all the GRW tankers radiographed. There was a wide variation, from 7.5 % to 60.1 % of the weld length radiographed being rejected for J2580 and J3910, respectively. These tankers were selected as the best and worst case GRW tankers for the topple test. GRW tanker J3857, selected for fatigue data collection, was at the lower end of rejection, having 13.8 % of the total length of weld radiographed rejected. The range and average for all GRW tankers radiographed was 7.5 % to 60.7 % and 37.4 %, respectively.

The GRW tankers selected for test were all fully ADR inspected and, where necessary, remedial work was undertaken to make the tankers ADR compliant, roadworthy and loadworthy. GRW tanker J3857 was inspected for roadworthiness and subjected to an MOT, subjected to ADR periodic inspection (with manway bolts and gaskets replaced and refitted), and certified gas-free before collecting on-road fatigue data. GRW tankers J2580 and J3910 were both subjected to ADR periodic inspection (with minor repairs to manway lids), removal of parts not needed for test, release of kingpin plate bolts, and gas-free certification for transport before delivery to HSL. After preparation for topple test at HSL, both tankers were subjected to a pressure test to the ADR periodic inspection requirements with pressure relief valves checked and adjusted, and manway bolts and gaskets replaced and refitted to ensure that the tankers were both fully sealed and loadworthy before topple test. In addition, the GRW tankers selected for topple test were radiographed a second time, which confirmed the lack of fusion indications already observed. These tankers were also subjected to internal surveys of their fillet welds. GRW tanker J3910 was also subject to an internal survey of circumferential weld misalignment and an external survey of circumferential weld caps using laser scanning techniques, the data from which was analysed within WP2.

A suitable 8-compartment 40,000 litre petroleum road tanker of aluminium construction in roadworthy and loadworthy condition was sourced for the proof of concept topple test.

Two accident-damaged GRW tankers, J3217 with rear damage, which was procured, and J3146 with front damage, have been laser scanned to provide dimensional information on the damage and physical samples have been taken for mechanical testing and post-mortem activities in WP2.

Physical samples for mechanical testing and post-mortem activities in WP2 were also taken from the topple tested GRW tankers; from the rear of the undamaged nearside and damaged off-side of J2580 and the front of the damaged off-side of GRW tanker J3910.

7 REFERENCES

[1] EN ISO 10042: 2005, Welding. Arc-welded joints in aluminium and its alloys. Quality levels for imperfections.

8 APPENDIX 1 - INSPECTIONS, SURVEYS AND WORK CONDUCTED ON GRW TANKERS J2580, J3910 AND J3857

8.1 GRW TANKER J2580

- Full ADR inspection and remedial work.
- Radiography of all bands.
- ADR re-inspection after radiography and remedial work (minor repairs to manway lids).
- Removal of some items not needed for topple test before delivery to HSL.
- Second radiography of offside bands F/8, G/8 and H/8 at HSL.
- Internal survey of fillet welds and bands at HSL before test.
- Pneumatic pressure test and resealing of manway lids at HSL before test (pressure relief valves checked and adjusted, some manway bolts and gaskets replaced).
- Pneumatic pressure test at HSL after test.

8.2 GRW TANKER J3910

- Full ADR inspection and remedial work.
- Radiography of all bands.
- ADR re-inspection after radiography and remedial work (minor repairs to manway lids).
- Second radiography of all bands.
- Removal of some items not needed for topple test before delivery to HSL.
- Internal survey of fillet welds and misalignment of circumferential welds for all bands at HSL before test.
- External laser scan survey of weld caps for all bands at HSL before test.
- Pneumatic pressure test and resealing of manway lids at HSL before test (pressure relief valves checked and adjusted, some manway bolts and gaskets replaced).
- Pneumatic pressure test at HSL after test.

8.3 GRW TANKER J3857

- Radiography of all bands prior to project.
- Roadworthiness inspection, MOT and remedial work.
- Full ADR inspection and remedial work (manway bolts and gaskets replaced and refitted).
- Preparation of tanker for on-road lifecycle data gathering by TWI.
- Removal of TWI instrumentation after on-road lifecycle data gathering.
- Minor work to restore tanker to agreed condition before return to owner.

9 APPENDIX 2 - COMPARISON BETWEEN TANKERS AND SUMMARY OF INDIVIDUAL TANKER RADIOGRAPHY

9.1 COMPARISON BETWEEN TANKERS

Tanker No.	J4171	J3910	J3909	J3861	J3857	J3564	J3029	J2946	J2580	J2297	J2080	J2079	cumlative
Linear length tested (cm)	4139	3065	3075	4626	4423	4402	2984	3274	3183	4075	3771	3861	44878
Linear length rejected (cm)	2058.5	1840	737	1603	609	1222	1379	933	239	2475	1801.5	1897	16794
% rejected	49.7	60.1	24.0	34.7	13.8	27.8	46.2	28.5	7.5	60.7	47.8	49.1	37.4
	10 bands	8 bands	8 Bands	10 bands	10 bands	10 bands	8 Bands	8 Bands	8 bands	10 bands	10 bands	10 bands	

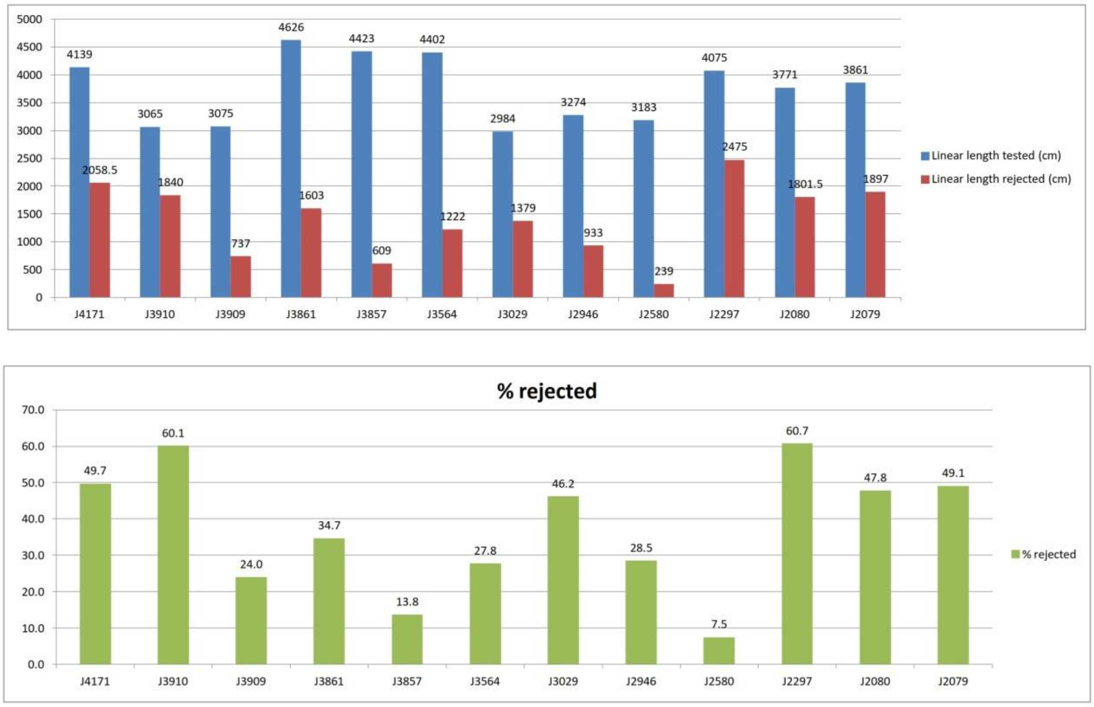


Figure A2-1 Overall radiograph lengths and percentage rejected for different tankers.

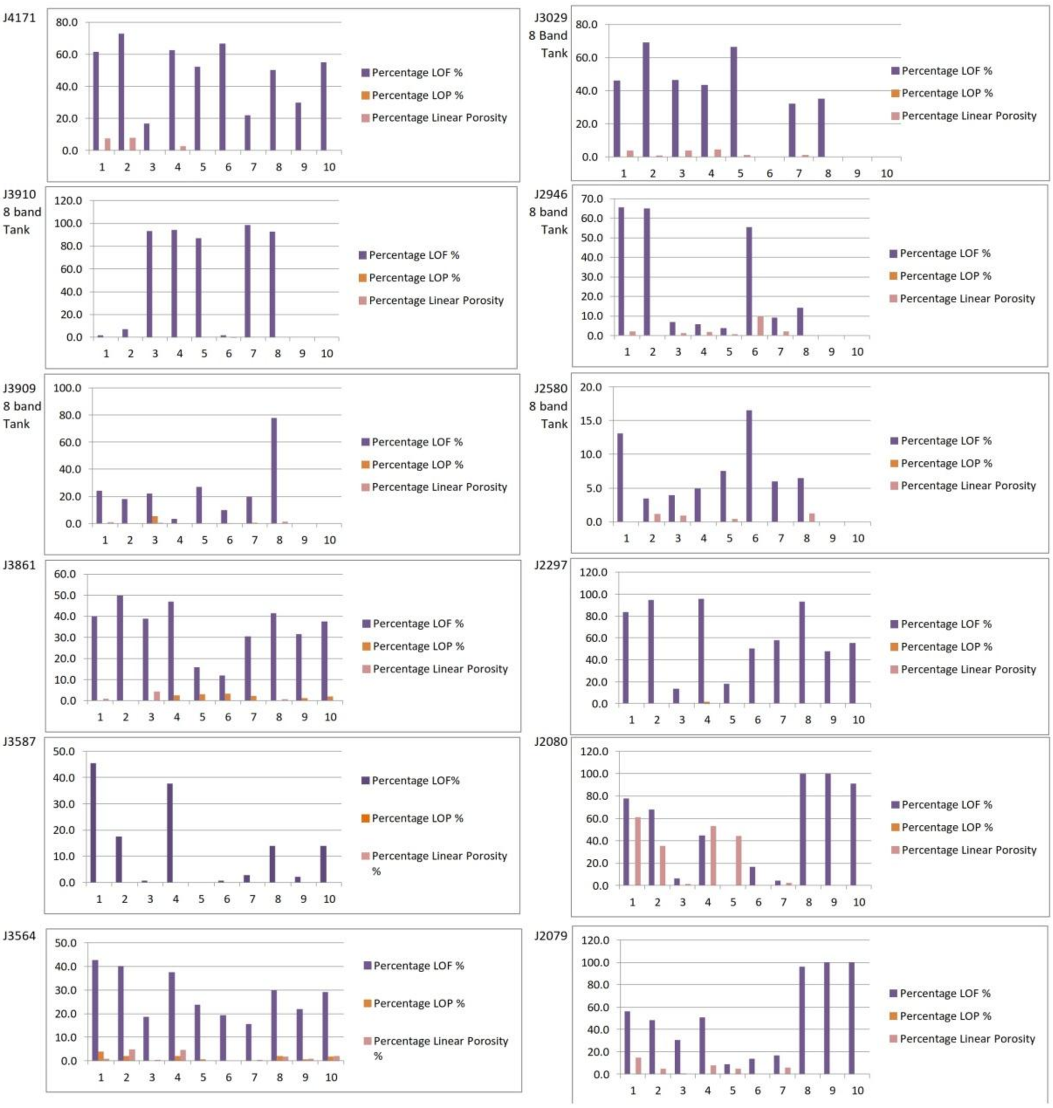


Figure A2-2 Percentage rejected by band for different tankers

9.2 SUMMARY OF INDIVIDUAL TANKER RADIOGRAPHY

Tanker Number J4171

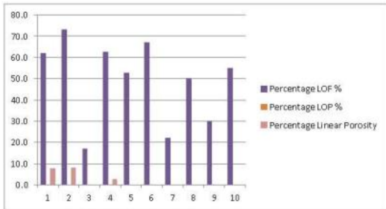
	CW Ref.	1	2	3	4	5	6	7	8		10
Linear weld length		450	415	430	422	448	439	430	379	284	442
linear defect length	LOF	278	303	72.5	264	235	293	95	190	85	243
Percentage	LOF %	**61.8**	**73.0**	**16.9**	**62.6**	**52.5**	**66.7**	**22.1**	**50.1**	**29.9**	**55.0**
linear defect length	LOP	0	0	0	0	0	0	0	0	0	0
Percentage	LOP %	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
linear defect length	Linear Porosity	34	33	0	11	0	0	0	0	0	0
Percentage	Linear Porosity	7.6	8.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0

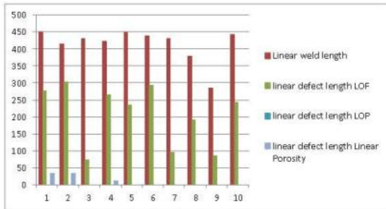
Cumlative for Circ. Welds

4139	Linear length tested (cm)
2058.5	Linear length rejected (cm)
49.7	% rejected

All dimensions in centemeters

1	Linear wed	35	32	37	35	35	35	32	33	22	35	32	30	25	32					450 cm
	Lin LOF	32	21	30	21	9	26	13	1	15	28	18	30	15	19					278 cm
	Lin LOP																			0 cm
	Lin Porosity		2	4					8		13				7					34 cm
2	Linear wed	27	35	33	28	31	36	34	16	35	35	35	38	32						415 cm
	Lin LOF	14	33	34	28	25	12	8	16	20	12	34	35	32						303 cm
	Lin LOP																			0 cm
	Lin Porosity		8					6	2	5	12									33 cm
3	Linear wed	28	30	37	30	35	38	38	18	35	34	37	35	35						430 cm
	Lin LOF	10	5	9		3	5	5		6	6.5	20	3							72.5 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
4	Linear wed	35	35	30	33	27	35	35	22	35	39	32	36	28						422 cm
	Lin LOF	17	13	23	19	19	2	3	14	25	36	27	36	30						264 cm
	Lin LOP																			0 cm
	Lin Porosity									5		6								11 cm
5	Linear wed	35	39	36	35	32	38	38	20	35	35	35	35	35						448 cm
	Lin LOF	20		7		1	26	17	20	21	35	24	35	29						235 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
6	Linear wed	35	35	35	35	28	37	37	20	37	35	35	35	35						439 cm
	Lin LOF	31	11	28	35	15	14	24	16	37	28	7	24	23						293 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
7	Linear wed	26	35	35	35	35	38	37	14	36	36	38	33	32						430 cm
	Lin LOF	11	5	7		29	9	15		5			8	6						95 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
8	Linear wed	35	35	37	38	36	34	20	36	34	37	37								379 cm
	Lin LOF	3	24	18	5	6	10	20	34	15	24	31								190 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
9	Linear wed	36	34	37	36				35	35	35	36								284 cm
	Lin LOF	19	18	10	6				4	11	9	8								85 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
10	Linear wed	37	31	34	36	35	35	35	34	34	30	32	31	38						442 cm
	Lin LOF	12	20	17	21	26	15		33	8	19	32	23	17						243 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm





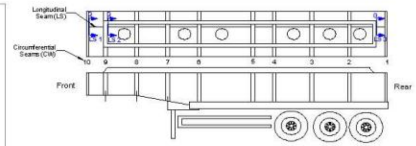


Figure A2-3 J4171 Radiography summary

Tanker Number J3910

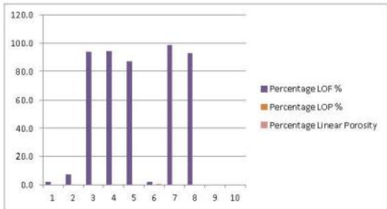
CW Ref.		1	2	3	4	5	6	7	8		
Linear weld length		340	424	428	428	428	368	368	280		
linear defect length	LOF	6	30	400	403	372	6	363	260		
Percentage	LOF %	**1.8**	**7.1**	**93.5**	**94.2**	**86.9**	**1.6**	**98.6**	**92.9**		
linear defect length	LOP	0	0	0	0	0	0	0	0		
Percentage	LOP %	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**		
linear defect length	Linear Porosity	0	0	0	0	0	2	0	0		
Percentage	Linear Porosity	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0		

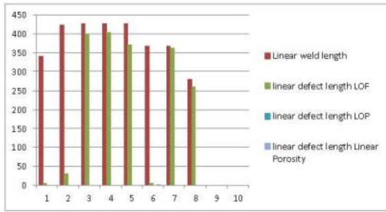
Cumlative for Circ. Welds

3064	Linear length tested (cm)
1840	Linear length rejected (cm)
60.1	% rejected

All dimensions in centemeters

1	Linear wed	35	35	35	35	30				35	35	35	35	30						340 cm
	Lin LOF	2										2		2						6 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
2	Linear wed	35	35	35	35	30	35	35	14	35	35	35	35	30						424 cm
	Lin LOF	3	3					22					2							30 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
3	Linear wed	35	35	35	35	30	35	35	18	35	35	35	35	30						428 cm
	Lin LOF	35	35	35	35	30	26	35	14	35	28	27	35	30						400 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
4	Linear wed	35	35	35	35	30	35	35	18	35	35	35	35	30						428 cm
	Lin LOF	35	35	35	35	30	35	25	18	35	35	35	25	25						403 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
5	Linear wed	35	35	35	35	30	35	35	18	35	35	35	35	30						428 cm
	Lin LOF	35	35	28	35	16	25	17	18	35	28	35	35	30						372 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
6	Linear wed	35	35	35	35	36	34	18	35	35	35	35								368 cm
	Lin LOF				3		3													6 cm
	Lin LOP																			0 cm
	Lin Porosity	2																		2 cm
7	Linear wed	35	35	35	35	36	34	18	35	35	35	35								368 cm
	Lin LOF	35	35	35	35	36	29	18	35	35	35	35								363 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
8	Linear wed	35	35	35	35				35	35	35	35								280 cm
	Lin LOF	35	35	35	30				30	35	35	25								260 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm





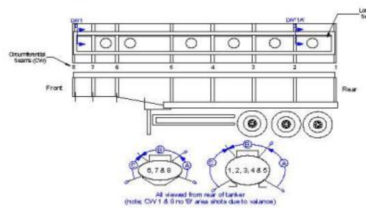


Figure A2-4 J3910 Radiography summary

Tanker Number J3909

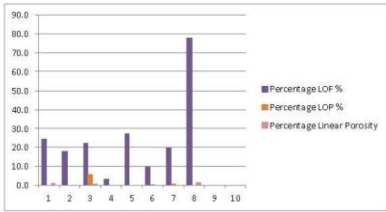
	CW Ref.	1	2	3	4	5	6	7	8		
Linear weld length		276	370	375	425	428	430	431	340		
linear defect length	LOF	67	66	83	14	116	42	85	264		
Percentage	LOF %	**24.3**	**17.8**	**22.1**	**3.3**	**27.1**	**9.8**	**19.7**	**77.6**		
linear defect length	LOP	0	0	21	0	0	1	2	0		
Percentage	LOP %	**0.0**	**0.0**	**5.6**	**0.0**	**0.0**	**0.2**	**0.5**	**0.0**		
linear defect length	Linear Porosity	3	0	2	0	0	0	0	5		
Percentage	Linear Porosity	1.1	0.0	0.5	0.0	0.0	0.0	0.0	1.5		

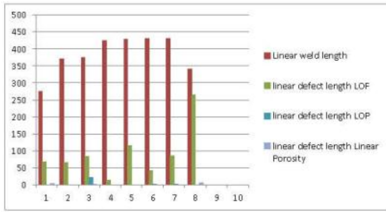
Cumlative for Circ. Welds

3075	Linear length tested (cm)
737	Linear length rejected (cm)
24.0	% rejected

All dimensions in centemeters

1	Linear wed	32	37	30	33					37	35	35	37							276 cm
	Lin LOF	10	13	10	33						1									67 cm
	Lin LOP																			0 cm
	Lin Porosity				3															3 cm
2	Linear wed	35	37	35	33		36	34	20	35	35	35	35							370 cm
	Lin LOF	11		1			35	3		16										66 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
3	Linear wed	35	37	33	35		36	35	26	33	35	35	35							375 cm
	Lin LOF	1	6	14	30			8		11	5		8							83 cm
	Lin LOP											21								21 cm
	Lin Porosity			2																2 cm
4	Linear wed	35	34	33	35	30	36	36	16	35	35	35	35	30						425 cm
	Lin LOF	3					4	4						3						14 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
5	Linear wed	35	37	35	35	28	38	34	16	35	35	35	35	30						428 cm
	Lin LOF	10	13		20	28	20			21			4							116 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
6	Linear wed	35	37	35	30	29	36	36	22	35	35	35	35	30						430 cm
	Lin LOF		9	4				8	2					19						42 cm
	Lin LOP							1												1 cm
	Lin Porosity																			0 cm
7	Linear wed	35	35	37	33	33	36	32	18	35	35	35	37	30						431 cm
	Lin LOF	11	25	20	25		4													85 cm
	Lin LOP						2													2 cm
	Lin Porosity																			0 cm
8	Linear wed	35	35	33	35	30				35	37	38	35	27						340 cm
	Lin LOF	15	35	20	33	28				28	37	38	30							264 cm
	Lin LOP																			0 cm
	Lin Porosity												5							5 cm





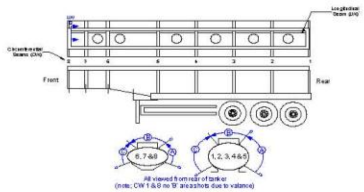


Figure A2-5 J3909 Radiography summary

Tanker Number J3861

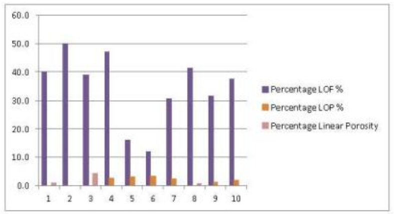
CW Ref.		1	2	3	4	5	6	7	8		10
Linear weld length		508	461	455	457	433	451	505	452	425	479
linear defect length	LOF	203	230	177	215	69	54	154	187	134	180
Percentage	LOF %	**40.0**	**49.9**	**38.9**	**47.0**	**15.9**	**12.0**	**30.5**	**41.4**	**31.5**	**37.6**
linear defect length	LOP	0	0	0	12	13	15	12	0	5	9
Percentage	LOP %	**0.0**	**0.0**	**0.0**	**2.6**	**3.0**	**3.3**	**2.4**	**0.0**	**1.2**	**1.9**
linear defect length	Linear Porosity	5	0	20	0	0	0	0	3	0	0
Percentage	Linear Porosity	1.0	0.0	4.4	0.0	0.0	0.0	0.0	0.7	0.0	0.0

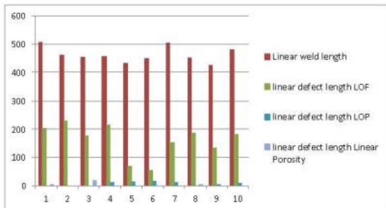
Cumlative for Circ. Welds

4626	Linear length tested (cm)
1603	Linear length rejected (cm)
34.7	% rejected

All dimensions in centemeters

1	Linear wed	32	32	36	36	35	30	33	35	34	32	34	33	36	35	35				508 cm
	Lin LOF			10			19	15	9	25	30	19	17	5	21	33				203 cm
	Lin LOP																			0 cm
	Lin Porosity						5													5 cm
2	Linear wed	35	35	35	35	35	36	36	37	35	35	35	35	37						461 cm
	Lin LOF	14	1			27	32	30	18	35	35	16	7	15						230 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
3	Linear wed	35	30	35	35	36	36	36	40	36	34	35	33	34						455 cm
	Lin LOF	3	30	35	35	35	3	5	7	2	1			21						177 cm
	Lin LOP																			0 cm
	Lin Porosity							10	10											20 cm
4	Linear wed	35	35	35	35	35	35	37	36	35	34	35	35	35						457 cm
	Lin LOF	14	12	14	28	5	20	32	32	25	25	8								215 cm
	Lin LOP			8				2					2							12 cm
	Lin Porosity																			0 cm
5	Linear wed	35	35	35	35	33	36	36	18	35	35	35	35	30						433 cm
	Lin LOF		13	13		16	2	10	10	2		3								69 cm
	Lin LOP						6					7								13 cm
	Lin Porosity																			0 cm
6	Linear wed	35	35	35	35	32	34	36	36	35	37	33	35	33						451 cm
	Lin LOF		13	4	4	6	11	8	3					5						54 cm
	Lin LOP						1	4		2	7	1								15 cm
	Lin Porosity																			0 cm
7	Linear wed	35	35	35	35	35	35	36	36	16	35	35	30	35	35	37				505 cm
	Lin LOF	7	10	25	2	24	27	5	8				20	7	6	13				154 cm
	Lin LOP										9	3								12 cm
	Lin Porosity																			0 cm
8	Linear wed	35	35	35	35	30	36	36	32	35	35	35	35	38						452 cm
	Lin LOF	35	35	2		1	16	10	12	24	12	30	10							187 cm
	Lin LOP																			0 cm
	Lin Porosity									3										3 cm
9	Linear wed	35	35	35	35	37	35	30	23	35	35	35	35	20						425 cm
	Lin LOF	5	4		26	23	3		2	3	8	16	24	20						134 cm
	Lin LOP									5										5 cm
	Lin Porosity																			0 cm
10	Linear wed	30	35	34	35	33	32	36	37	37	35	35	32	33	35					479 cm
	Lin LOF	3	15	19	13	27	20	16	18	10	9	5	7	8	10					180 cm
	Lin LOP								9											9 cm
	Lin Porosity																			0 cm





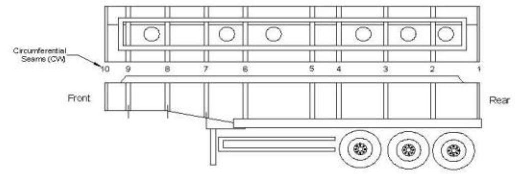


Figure A2-6 J3861 Radiography summary

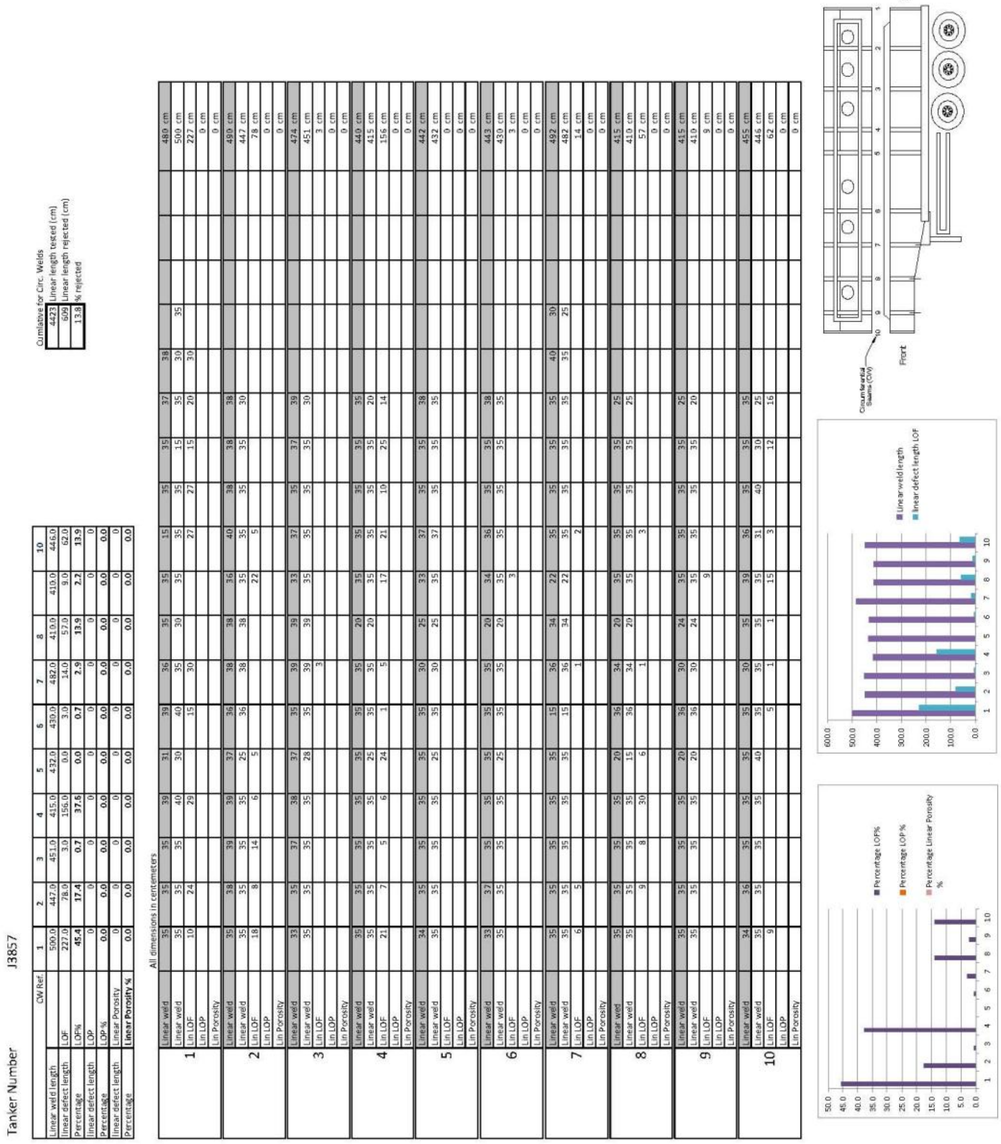


Figure A2-7 J3857 Radiography summary

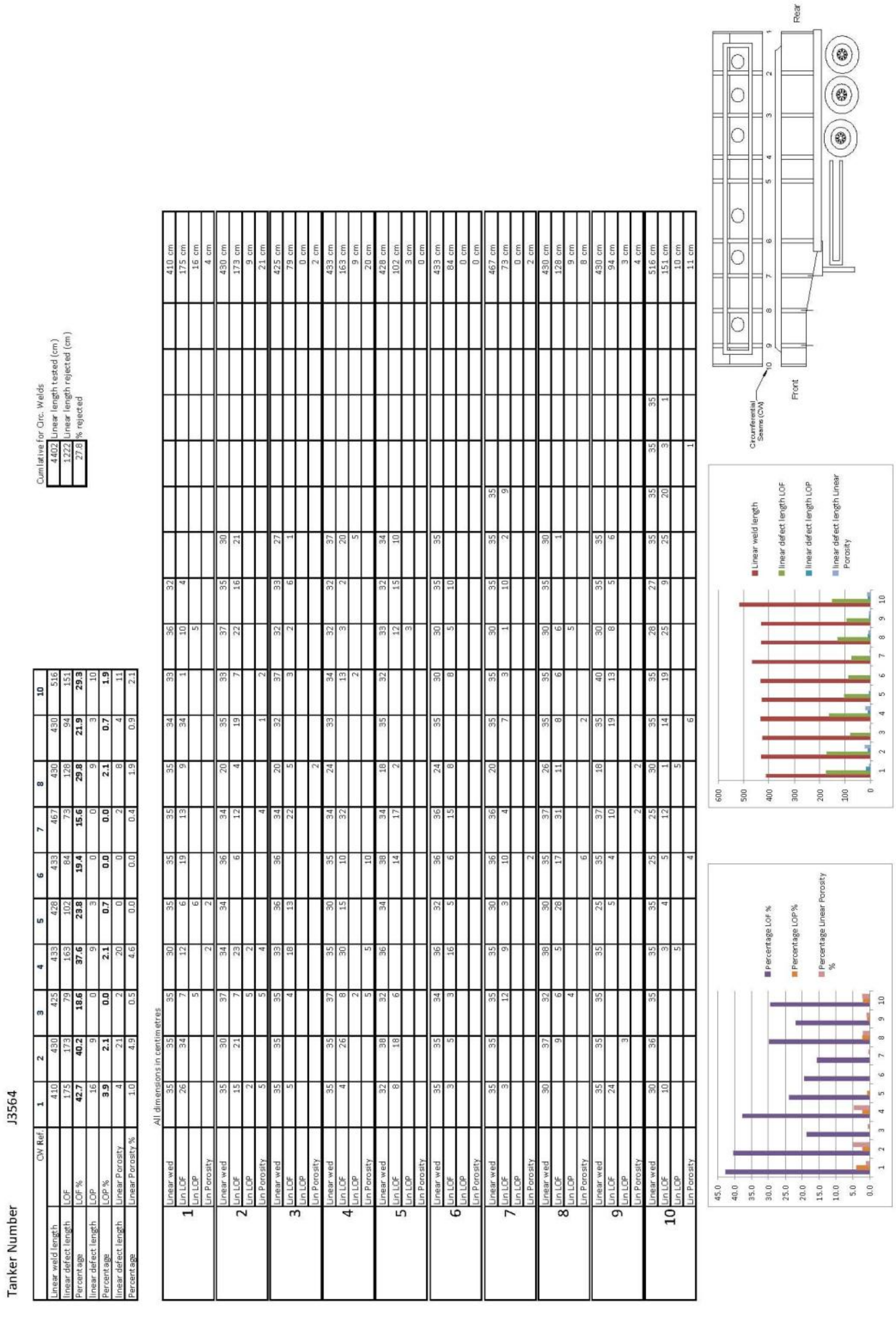


Figure A2-8 J3564 Radiography summary

Tanker Number J3029

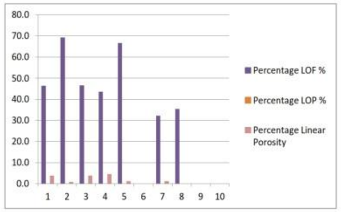
	CW Ref.	1	2	4	5	6	3	7	8		
Linear weld length		287	375	387	381	333	0	330	246		
linear defect length	LOF	133	260	180	166	222	0	106	87		
Percentage	LOF %	**46.3**	**69.3**	**46.5**	**43.6**	**66.7**		**32.1**	**35.4**		
linear defect length	LOP	0	0	0	0	0		0	0		
Percentage	LOP %	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**		**0.0**	**0.0**		
linear defect length	Linear Porosity	11	3	15	17	4		4	0		
Percentage	Linear Porosity	3.8	0.8	3.9	4.5	1.2		1.2	0.0		

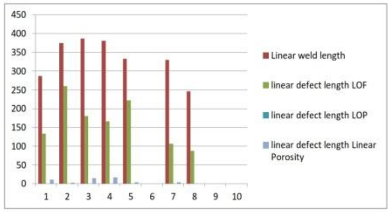
Cumlative for Circ. Welds

2708	Linear length tested (cm)
1250	Linear length rejected (cm)
46.2	% rejected

All dimensions in centemeters

1	Linear wed	30	36	35	20							32	36	32	34	32				287 cm
	Lin LOF	14	23	23	9							26	15		9	14				133 cm
	Lin LOP																			0 cm
	Lin Porosity													5		6				11 cm
2	Linear wed	35	35	35	20			36	34	14		32	34	33	35	32				375 cm
	Lin LOF	35	20	35	20			24	51			22	15	8	4	26				260 cm
	Lin LOP																			0 cm
	Lin Porosity		3																	3 cm
3	Linear wed	31	32	34	26			36	34	10		36	32	32	34	32				369 cm
	Lin LOF	14						16	20	3		15	2	1	10	15				96 cm
	Lin LOP																			0 cm
	Lin Porosity			3	6															9 cm
4	Linear wed	35	36	32	26			34	34	20		36	34	36	34	30				387 cm
	Lin LOF		6	6	17			10	19	12		21	15	21	29	24				180 cm
	Lin LOP																			0 cm
	Lin Porosity				5			6		4										15 cm
5	Linear wed	20	26	34	35	14		36	34	18		36	32	30	6	34	26			381 cm
	Lin LOF		6	16	26	12		13	22	15		22	7	15			12			166 cm
	Lin LOP																			0 cm
	Lin Porosity	1						9	5								2			17 cm
6	Linear wed	36	38	34				36	36	12		34	35	36	36					333 cm
	Lin LOF	16	28	34				32	33	10		21	28	12	8					222 cm
	Lin LOP																			0 cm
	Lin Porosity														4					4 cm
7	Linear wed	34	38	34				34	36	18		36	36	34	30					330 cm
	Lin LOF	14	17					21	13			8	12	6	15					106 cm
	Lin LOP																			0 cm
	Lin Porosity							4												4 cm
8	Linear wed	34	36	38								30	18	22	36	32				246 cm
	Lin LOF	7	25	25								7	13	4	2	4				87 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm





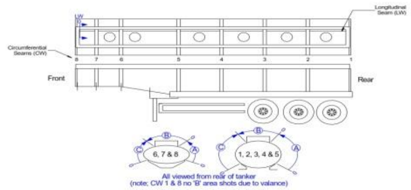


Figure A2-9 J3029 Radiography summary

Tanker Number J2946

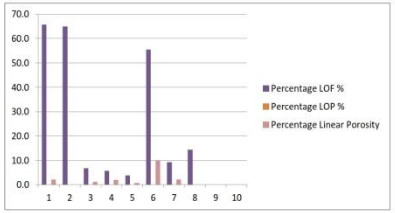
	CW Ref.	1	2	3	4	5	6	7	8		
Linear weld length		420	420	424	418	415	404	389	384		
linear defect length	LOF	276	273	29	24	16	224	36	55		
Percentage	LOF %	**65.7**	**65.0**	**6.8**	**5.7**	**3.9**	**55.4**	**9.3**	**14.3**		
linear defect length	LOP	0	0	0	0	0	0	0	0		
Percentage	LOP %	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**		
linear defect length	Linear Porosity	9	0	5	8	3	40	8	0		
Percentage	Linear Porosity	2.1	0.0	1.2	1.9	0.7	9.9	2.1	0.0		

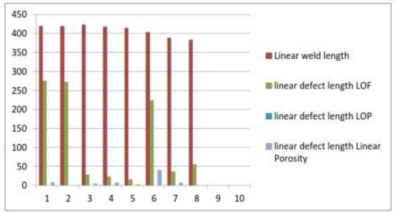
Cumlative for Circ. Welds

3274	Linear length tested (cm)
933	Linear length rejected (cm)
28.5	% rejected

All dimensions in centemeters

1	Linear wed	35	35	35	39	25		30	26	29		36	34	38	36	22				420 cm
	Lin LOF	32	9	31	23	18		7	18	20		36	22	38	22					276 cm
	Lin LOP																			0 cm
	Lin Porosity											3	6							9 cm
2	Linear wed	35	35	35	32	26		34	26	30		37	36	36	36	22				420 cm
	Lin LOF	33	32	35	24	20		4	12	14		23	18	26	20	12				273 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
3	Linear wed	35	37	36	36	26		30	30	30		34	36	36	36	22				424 cm
	Lin LOF			3				11	11				4							29 cm
	Lin LOP																			0 cm
	Lin Porosity	3							2											5 cm
4	Linear wed	35	37	36	34	30		30	32	28		34	36	32	34	20				418 cm
	Lin LOF	8	2					10	4											24 cm
	Lin LOP																			0 cm
	Lin Porosity												8							8 cm
5	Linear wed	36	36	36	32	22		32	30	28		36	34	36	36	21				415 cm
	Lin LOF							12	4											16 cm
	Lin LOP																			0 cm
	Lin Porosity								3											3 cm
6	Linear wed	36	36	34	38	12		30	30	34		36	36	35	37	10				404 cm
	Lin LOF	7	28	20	17	7		18	21	33		25	18	10	10	10				224 cm
	Lin LOP																			0 cm
	Lin Porosity				4					34				2						40 cm
7	Linear wed	36	36	36	32	11		30	30	28		34	36	36	34	10				389 cm
	Lin LOF							12	14	2			8							36 cm
	Lin LOP																			0 cm
	Lin Porosity												8							8 cm
8	Linear wed	36	34	34	34	12		30	26	16		36	34	36	34	22				384 cm
	Lin LOF	15	12	28																55 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm





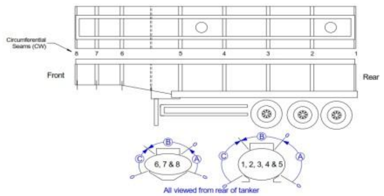


Figure A2-10 J2946 Radiography summary

Tanker Number J2580

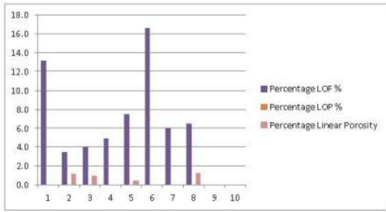
CW Ref.		1	2	3	4	5	6	7	8		
Linear weld length		320	433	428	428	453	393	403	325		
linear defect length	LOF	42	15	17	21	34	65	24	21		
Percentage	LOF %	**13.1**	**3.5**	**4.0**	**4.9**	**7.5**	**16.5**	**6.0**	**6.5**		
linear defect length	LOP	0	0	0	0	0	0	0	0		
Percentage	LOP %	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**		
linear defect length	Linear Porosity	0	5	4	0	2	0	0	4		
Percentage	Linear Porosity	0.0	1.2	0.9	0.0	0.4	0.0	0.0	1.2		

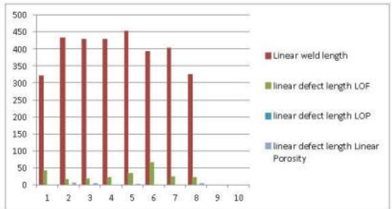
Cumlative for Circ. Welds

3183	Linear length tested (cm)
239	Linear length rejected (cm)
7.5	% rejected

All dimensions in centemeters

1	Linear wed	35	20	35	35	25				35	35	35	40	25						320 cm
	Lin LOF	32		5		5														42 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
2	Linear wed	35	35	35	35	35	32	36	20	35	35	35	40	25						433 cm
	Lin LOF					3		1				1	1	9						15 cm
	Lin LOP																			0 cm
	Lin Porosity	5																		5 cm
3	Linear wed	35	35	35	35	30	38	34	16	35	35	35	35	30						428 cm
	Lin LOF	8			4			1	4											17 cm
	Lin LOP																			0 cm
	Lin Porosity													4						4 cm
4	Linear wed	35	35	35	35	30	36	36	16	35	35	35	35	30						428 cm
	Lin LOF		3		5	7		5				1								21 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
5	Linear wed	35	35	35	40	15	35	38	34	16	35	35	35	35	30					453 cm
	Lin LOF		3		8		1							14	8					34 cm
	Lin LOP																			0 cm
	Lin Porosity					2														2 cm
6	Linear wed	35	35	35	35		34	36	18	35	35	35	35	25						393 cm
	Lin LOF	5	19	1	25			1		3		2	3	6						65 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
7	Linear wed	35	35	35	35	20	38	34	16	35	35	35	35	15						403 cm
	Lin LOF		3		11			2		3				5						24 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
8	Linear wed	35	35	35	40	20				35	35	35	35	20						325 cm
	Lin LOF				1	1				12			7							21 cm
	Lin LOP																			0 cm
	Lin Porosity				4															4 cm





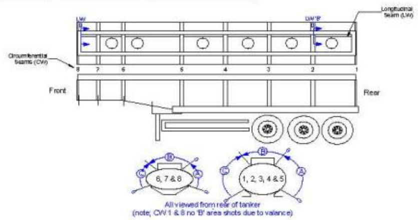


Figure A2-11 J2580 Radiography summary

Tanker Number J2297

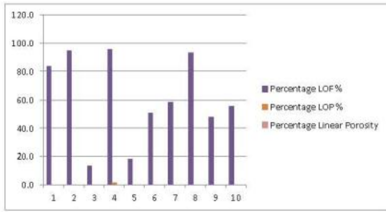
	CW Ref.	1	2	3	4	5	6	7	8		10
Linear weld length		385	407	413	406	400	397	465	390	397	415
linear defect length	LOF	321	385	56	388	72	200	270	363	190	230
Percentage	LOF %	**83.4**	**94.6**	**13.6**	**95.6**	**18.0**	**50.4**	**58.1**	**93.1**	**47.9**	**55.4**
linear defect length	LOP	0	0	0	6	0	0	0	0	0	0
Percentage	LOP %	**0.0**	**0.0**	**0.0**	**1.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
linear defect length	Linear Porosity	0	0	0	0	0	0	0	0	0	0
Percentage	Linear Porosity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

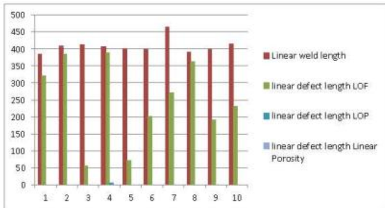
Cumlative for Circ. Welds

4075	Linear length tested (cm)
2475	Linear length rejected (cm)
60.7	% rejected

All dimensions in centemeters

1	Linear wed	35	35	35	35	22	35	30	32	36	35	35	20							385 cm
	Lin LOF	35	35	35	35	20	10	25	17	22	35	35	17							321 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
2	Linear wed	35	35	35	35	20	35	35	15	35	35	35	35	22						407 cm
	Lin LOF	35	35	35	33	19	31	35	15	35	35	35	20	22						385 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
3	Linear wed	35	35	35	35	20	35	35	15	35	35	35	35	28						413 cm
	Lin LOF		8						6	13	4	4	15	6						56 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
4	Linear wed	35	35	35	35	20	35	35	15	35	35	35	35	21						406 cm
	Lin LOF	28	35	35	35	20	30	35	9	35	35	35	35	21						388 cm
	Lin LOP			6																6 cm
	Lin Porosity																			0 cm
5	Linear wed	35	35	35	35	18	35	35	15	35	35	30	35	22						400 cm
	Lin LOF		9				9	7	8	10	10	14	5							72 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
6	Linear wed	35	35	35	35	10	35	35	15	35	35	35	35	22						397 cm
	Lin LOF	33	35	24	10	9	8	22	5	22	22		7	3						200 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
7	Linear wed	35	35	35	35	35	15	35	35	15	35	35	35	35	35	15				465 cm
	Lin LOF	25		5	32	31	6	18	4		35	35	16	19	35	9				270 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
8	Linear wed	35	35	35	35	20	35	35	15	34	35	35	35	6						390 cm
	Lin LOF	35	35	35	35	20	21	35	3	34	35	35	35	5						363 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
9	Linear wed	35	35	35	35	16	35	35	15	35	35	35	35	16						397 cm
	Lin LOF	35	35	25	7		25	25	9	2		8	14	5						190 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
10	Linear wed	35	35	35	35	17	35	35	15	35	35	35	35	33						415 cm
	Lin LOF	28		15	33	15	7	14	3	27	28	5	25	30						230 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm





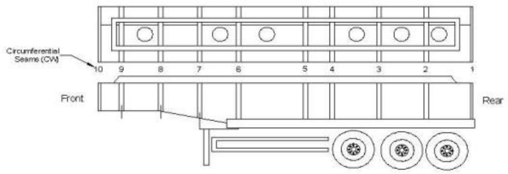


Figure A2-12 J2297 Radiography summary

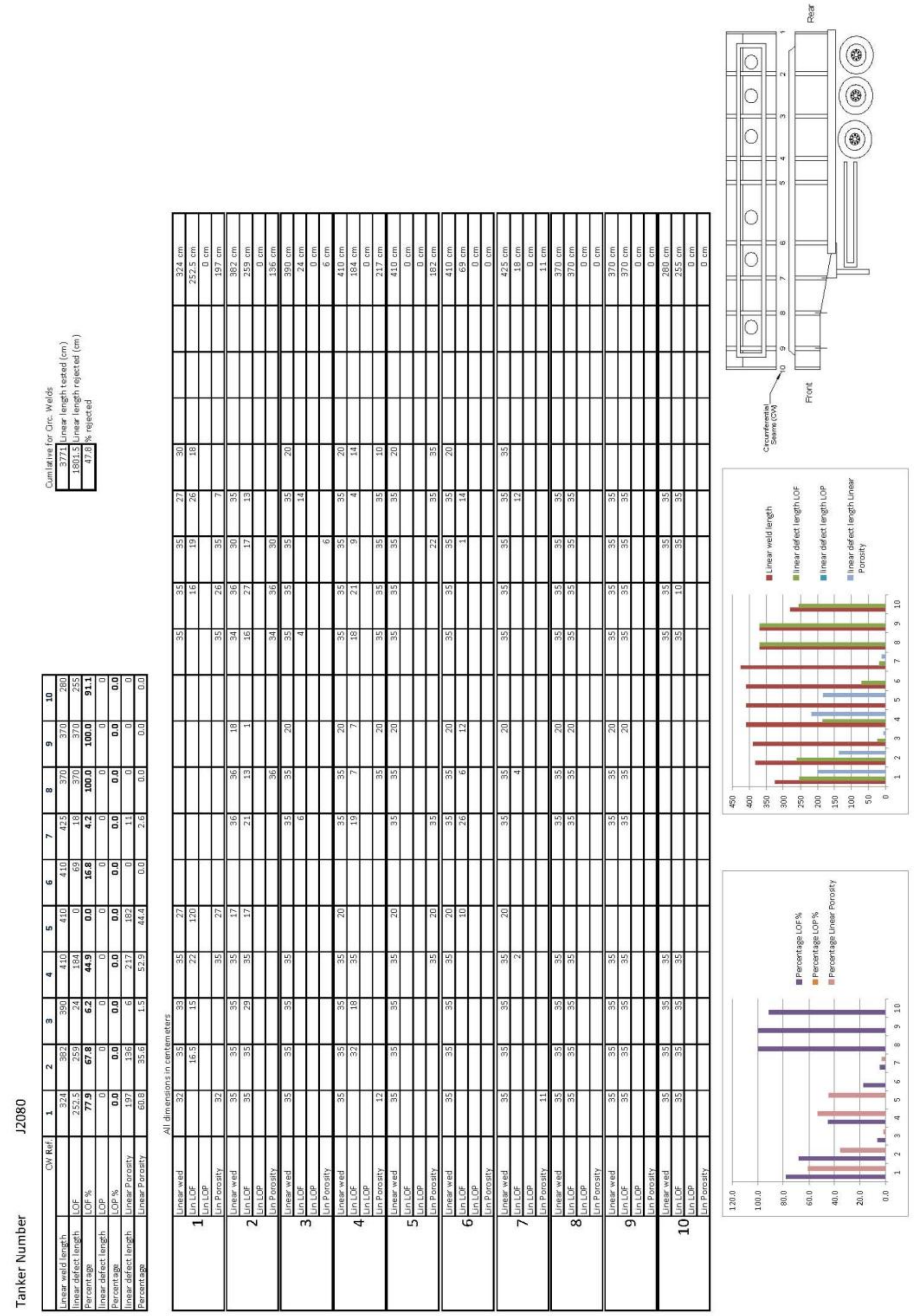


Figure A2-13 J2080 Radiography summary

Tanker Number J2079

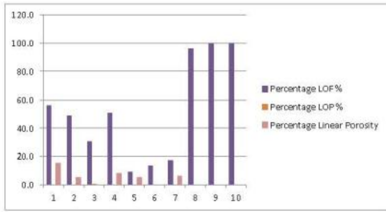
CW Ref.		1	2	3	4	5	6	7	8	9	10
Linear weld length		334	419	415	423	410	420	425	370	370	275
linear defect length	LOF	187	203	127	214	37	57	72	355	370	275
Percentage	LOF %	**56.0**	**48.4**	**30.6**	**50.6**	**9.0**	**13.6**	**16.9**	**95.9**	**100.0**	**100.0**
linear defect length	LOP	0	0	1.5	0	0	0	0	0	0	0
Percentage	LOP %	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
linear defect length	Linear Porosity	50	21	0	34	20	0	25	0	0	0
Percentage	Linear Porosity	15.0	5.0	0.0	8.0	4.9	0.0	5.9	0.0	0.0	0.0

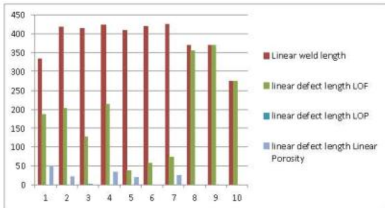
Cumlative for Circ. Welds

3861	Linear length tested (cm)
1897	Linear length rejected (cm)
49.1	% rejected

All dimensions in centemeters

1	Linear wed	35	34	35	35	25						35	35	35	35	30				334 cm
	Lin LOF	27	25	17	35	18						30	11	11	9	4				187 cm
	Lin LOP																			0 cm
	Lin Porosity					5							35	8	2					50 cm
2	Linear wed	35	35	35	35	20		35	34	20		35	35	35	30	35				419 cm
	Lin LOF	21	26	25	16	8		16	12			31	10	10	9	19				203 cm
	Lin LOP																			0 cm
	Lin Porosity				1					20										21 cm
3	Linear wed	35	35	35	35	20		35	35	20		30	35	35	35	30				415 cm
	Lin LOF	14		4	2	16		26	4	8		7	2	16	5	23				127 cm
	Lin LOP								1.5											1.5 cm
	Lin Porosity																			0 cm
4	Linear wed	35	34	33	35	20		35	34	34		33	35	35	35	25				423 cm
	Lin LOF	17	34	21	7	14		35				22	21	23	15	5				214 cm
	Lin LOP																			0 cm
	Lin Porosity				1							33								34 cm
5	Linear wed	35	35	35	35	20		35	35	20		35	35	35	35	20				410 cm
	Lin LOF	2						8	2			4		5	5	11				37 cm
	Lin LOP																			0 cm
	Lin Porosity					20														20 cm
6	Linear wed	35	35	35	35	20		35	35	20		35	35	35	35	30				420 cm
	Lin LOF			2	6	5		28		16										57 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
7	Linear wed	35	35	35	35	35		35	35	20		35	35	35	35	20				425 cm
	Lin LOF	1	8	4	10	3		3		20		4				19				72 cm
	Lin LOP																			0 cm
	Lin Porosity		5							20										25 cm
8	Linear wed	35	35	35	35			35	35	20		35	35	35	35					370 cm
	Lin LOF	35	35	35	35			31	24	20		35	35	35	35					355 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
9	Linear wed	35	35	35	35			35	35	20		35	35	35	35					370 cm
	Lin LOF	35	35	35	35			35	35	20		35	35	35	35					370 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm
10	Linear wed	35	35	35	35							35	35	35	30					275 cm
	Lin LOF	35	35	35	35							35	35	35	30					275 cm
	Lin LOP																			0 cm
	Lin Porosity																			0 cm





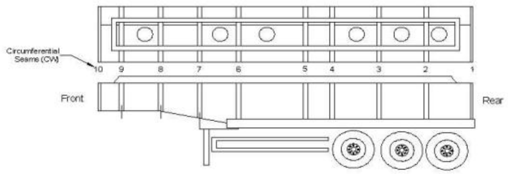


Figure A2-14 J2079 Radiography summary

10 APPENDIX 3 - RADIOGRAPHY INFORMATION FOR GRW TANKERS J2580 AND J3910

10.1 STARTING POSITIONS OF RADIOGRAPHY AND IMPACT AREA FOR GRW TANKERS J2850 AND J3910

Table A3-1 gives the approximate distances from the start of the radiography to the impact area for GRW tankers J2850 and J3910. As the edges of the impact area are not sharply defined, and the width of the impact area reduces from rear to front of the tankers, these distances are not exact. All distances relating to radiographs are over the curved surface of the tanker.

Table A3-1 Start of radiography to impact area distances for GRW tankers J2850 and J3910

All dimensions cm. As the impact area does not have clear edges these values have a variation of +/- 3cm
The width of the impact area (or length of the impact flat) reduces from rear (H/8) to front (A/8)

Band		**J2580 Radiography**		**J3910 Radiography**	
		Start to bottom of impact area	**Start to top of impact area**	**Start to bottom of impact area**	**Start to top of impact area**
M-1	H/8	14.5	114.5	16.5	115
M-2	G/8	16	-	19.5	-
M-3	F/8	19.5	-	22	-
M-4	E/8	22.5	-	23.5	-
M-5	D/8	24	-	23	-
M-6	C/8	26.5	-	22	-
M-7	B/8	28.5	-	29	-
M-8	A/8	26.5	101	34	102.5

10.2 GRW TANKER J2580

Table A3-2 gives the acceptance and rejection by the two radiography contractors for individual radiograph sections covering the offside band welds of GRW tanker J2580.

Table A3-2 Acceptance and rejection of individual radiograph sections for GRW tanker J2580

Band		Contractor 1			Contractor 2		
		Sections	Accept	Reject	Sections	Accept	Reject
M-1	H/8	5	2	3	6	0	6
M-2	G/8	5	3	2	6	0	6
M-3	F/8	5	3	2	6	0	6
M-4	E/8	5	2	3	-	-	-
M-5	D/8	6	2	3	-	-	-
M-6	C/8	4	0	4	-	-	-
M-7	B/8	5	3	2	-	-	-
M-8	A/8	5	3	2	-	-	-

Table A3-3 gives the radiography results by band for both contractors for GRW tanker J2580 – only partial radiography was conducted by contractor 2 so no overall figures are given. The overall rejection for offside and nearside combined was 9.8 % for contractor 1.

Table A3-3 Offside and full tanker rejection lengths for GRW tanker J2580

Band		Contractor 1				Contractor 2			
		Offside		Nearside		Offside		Nearside	
		Length radiographed (mm)	% rejected	Length radiographed (mm)	% rejected	Length radiographed (mm)	% rejected	Length radiographed (mm)	% rejected
M-1	H/8	1700	26.5	1700	0.0	1700	48.2	-	
M-2	G/8	1750	4.6	1700	6.5	1700	7.6	-	
M-3	F/8	1700	7.1	1700	2.4	1700	100.0*	-	
M-4	E/8	1700	8.8	1700	0.6	-		-	
M-5	D/8	2050	6.8	1700	18.8	-		-	
M-6	C/8	1400	33.6	1700	8.2	-		-	
M-7	B/8	1600	8.8	1700	10.6	-		-	
M-8	A/8	1650	7.9	1700	11.2	-		-	
Total		13550	12.4	13600	7.3	-		-	

* Intermittent Lack Of Fusion throughout all radiographs

10.3 GRW TANKER J3910

Table A3-4 gives the acceptance and rejection by the two radiography contractors for individual radiograph sections covering the offside band welds of GRW tanker J3910.

Table A3-4 Acceptance and rejection of individual radiograph sections for GRW tanker J3910

Band		Contractor 1			Contractor 2		
		Sections	Accept	Reject	Sections	Accept	Reject
M-1	H/8	5	4	1	6	2	4
M-2	G/8	5	2	3	6	1	5
M-3	F/8	5	0	5	6	0	6
M-4	E/8	5	0	5	6	0	6
M-5	D/8	5	0	5	6	0	6
M-6	C/8	4	2	2	6	3	3
M-7	B/8	4	0	4	6	0	6
M-8	A/8	4	0	4	6	0	6

Table A3-5 gives the radiography results by band for both contractors for GRW tanker J3910. The overall rejection for offside and nearside combined was 59.3 % for contractor 1 and 65.8 % for contractor 2 for J3910.

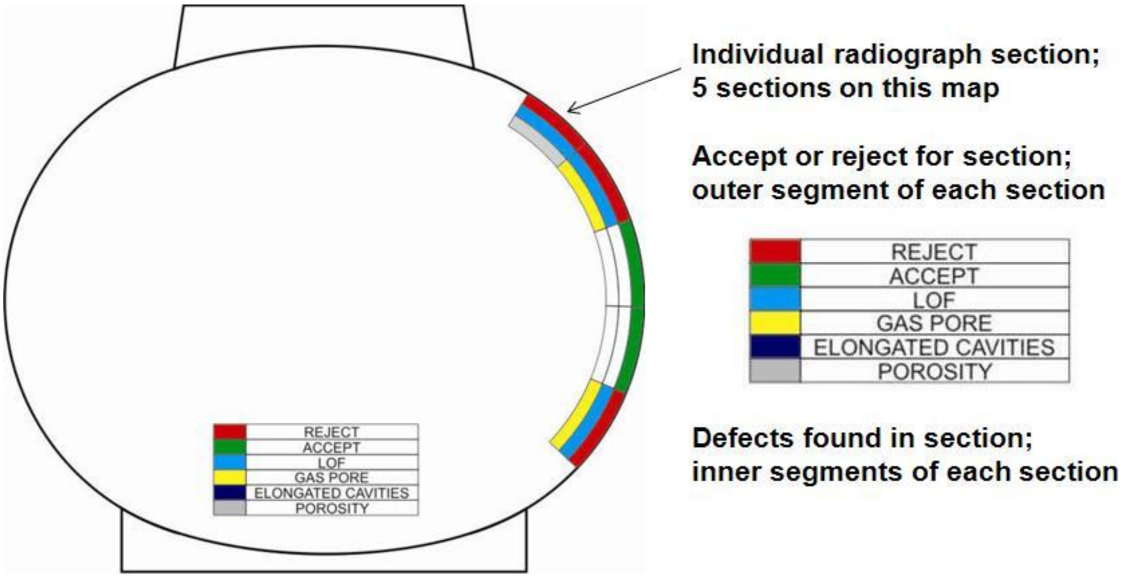
Table A3-5 Radiography results by band for GRW tanker J3910

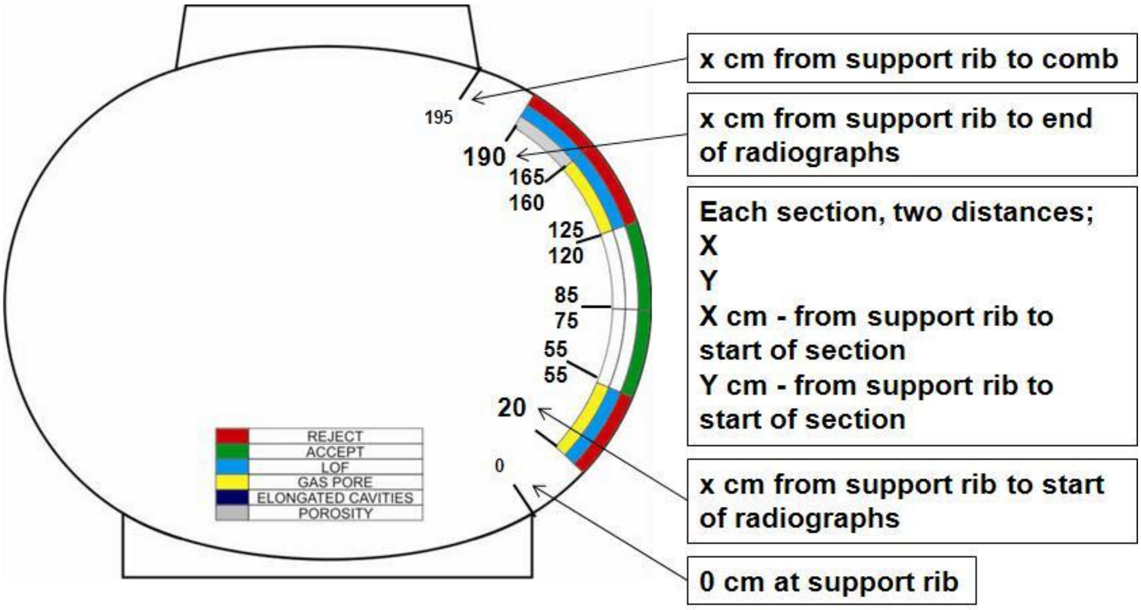
Band		Contractor 1				Contractor 2			
		Offside		Nearside		Offside		Nearside	
		Length radiographed (mm)	% rejected	Length radiographed (mm)	% rejected	Length radiographed (mm)	% rejected	Length radiographed (mm)	% rejected
		1700	1.2	1700	3.5	1700	7.1	1700	9.4
M-1	H/8	1700	5.3	1700	1.2	1700	10.0	1700	5.3
M-2	G/8	1700	100.0	1700	91.2	1750	100.0	1700	100.0
M-3	F/8	1700	100.0	1700	91.2	1800	100.0	1800	100.0
M-4	E/8	1700	85.3	1700	95.9	1800	93.3	1800	100.0
M-5	D/8	1400	3.6	1400	0.0	1650	32.1	1650	9.1
M-6	C/8	1400	100.0	1400	100.0	1650	97.0	1650	100.0
M-7	B/8	1400	85.7	1400	89.3	1600	100.0	1600	83.8
M-8	A/8	12700	59.9	12700	58.7	13650	67.8	13600	63.9
Total		25400	59.3			27250	65.8		

10.4 RADIOGRAPH MAPS

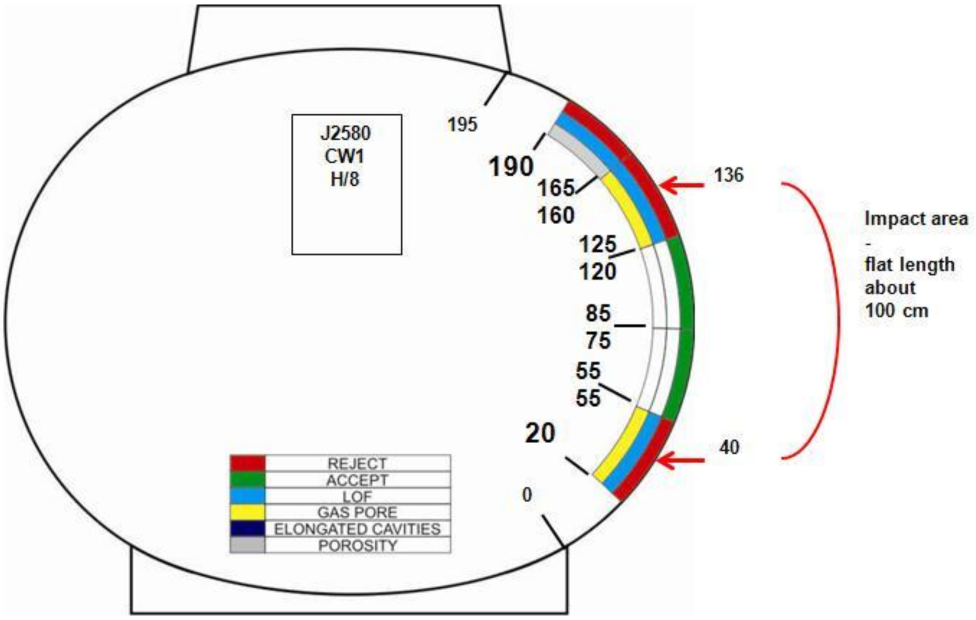
10.4.1 Explanation

PRELIMINARY MAPPING by HSL based on contractor 1 reports.
LOF = lack of fusion
All dimensions cm. Not to scale – indicative only.
As the impact area does not have clear edges these values have a variation of +/- 3cm.
The width of the impact area (or length of the impact flat) reduces from rear to front.

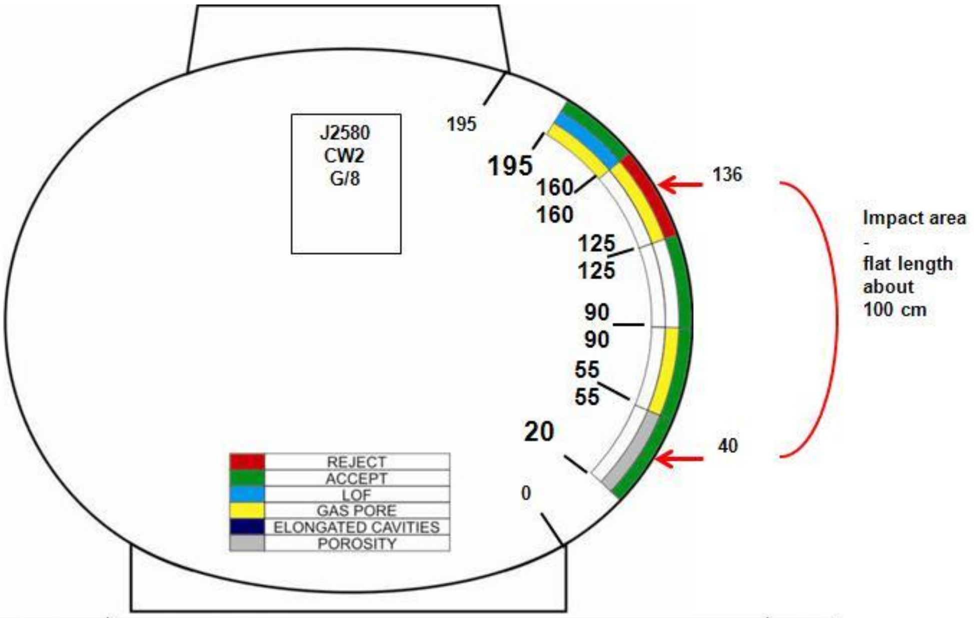




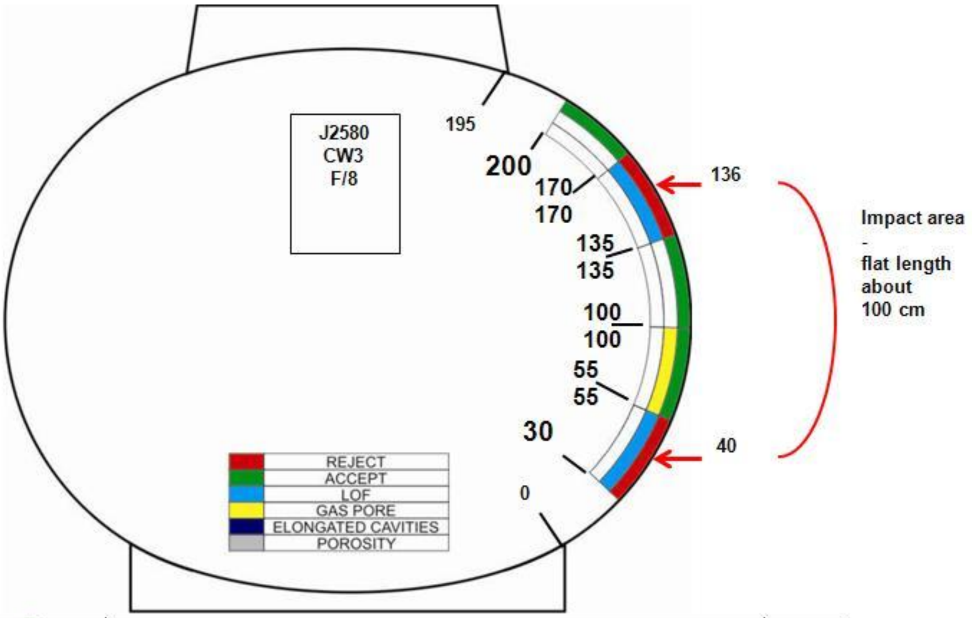
10.4.2 J2580 radiograph maps



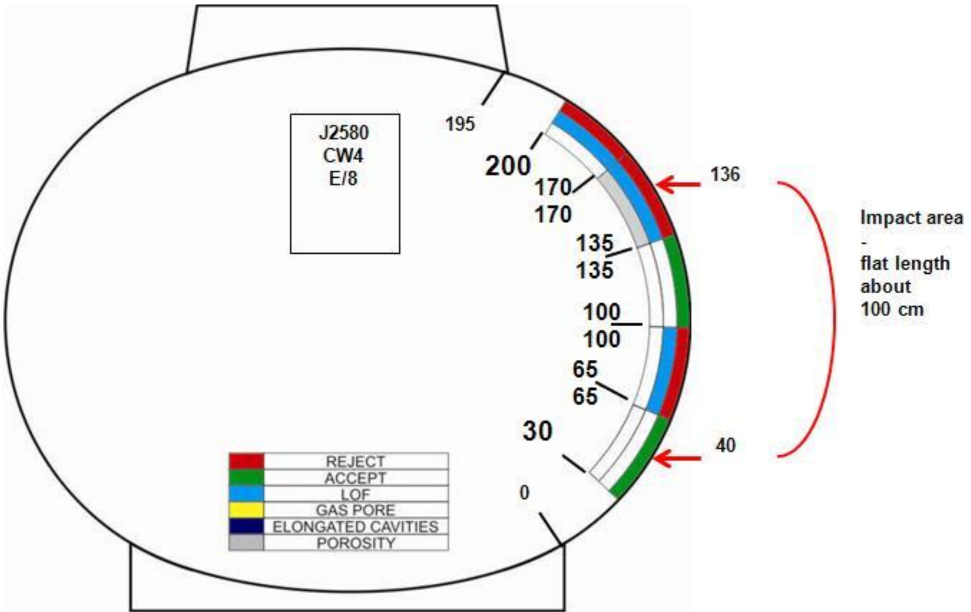
J2580	CW1(A)	0-35	LOF (intermittent full length). Gas Pore @ 34cm noted	Rej
J2580	CW1(A)	35-55		Acc
J2580	CW1(A)	65-100		Acc
J2580	CW1(A)	105-140	LOF 123 to 128cm. Gas Pore @ 119cm noted	Rej
J2580	CW1(A)	145-170	LOF 155 to 160cm. Porosity in fillet w eld noted	Rej



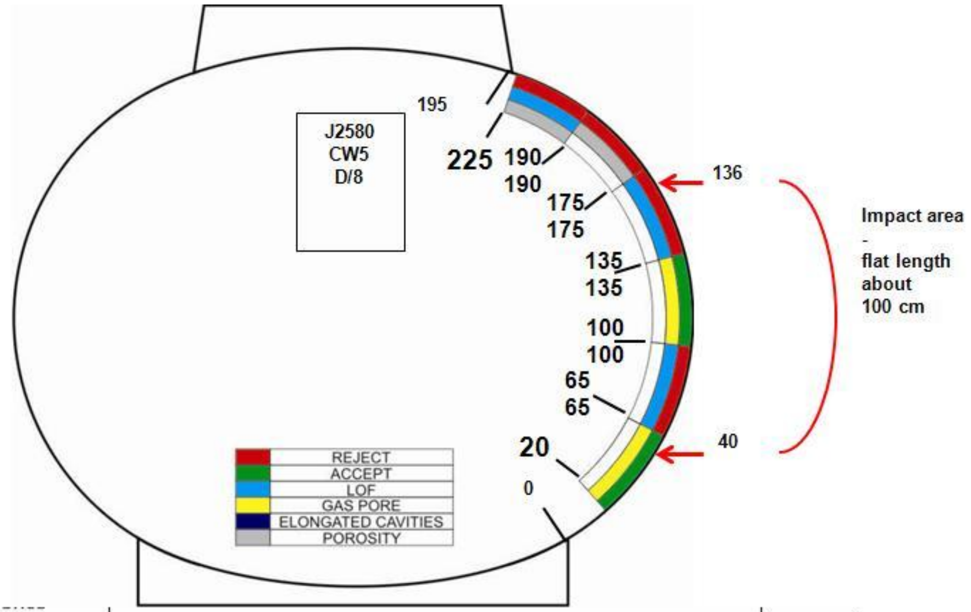
J2580	CW2(A)	0-35	Linear Porosity 15 to 20cm	Rej
J2580	CW2(A)	35-70	Gas Pores @ 3 & 61cm	Acc
J2580	CW2(A)	70-105		Acc
J2580	CW2(A)	105-140	Gas Pores @ 109 to 110cm & 118cm	Acc
J2580	CW2(A)	140-175	LOF 167 to 170cm. Gas pores @ 160 to 166cm	Rej



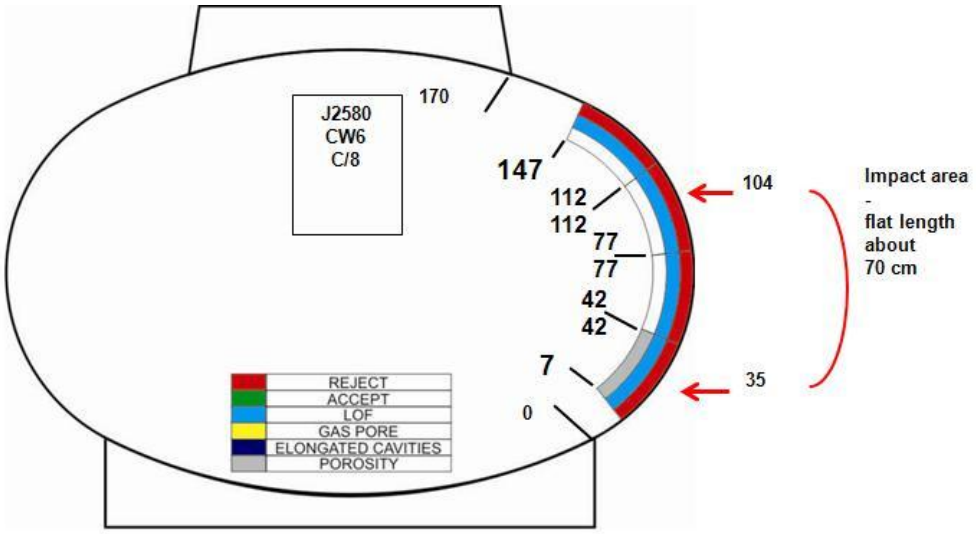
J2580	CW3(A)	10-45	LOF 22 to 26, 30 to 32, 34 to 36cm	Rej
J2580	CW3(A)	45-80	Gas pore @ 69cm noted	Acc
J2580	CW3(A)	80-115		Acc
J2580	CW3(A)	115-150	LOF 130 to 134cm	Rej
J2580	CW3(A)	150-180		Acc



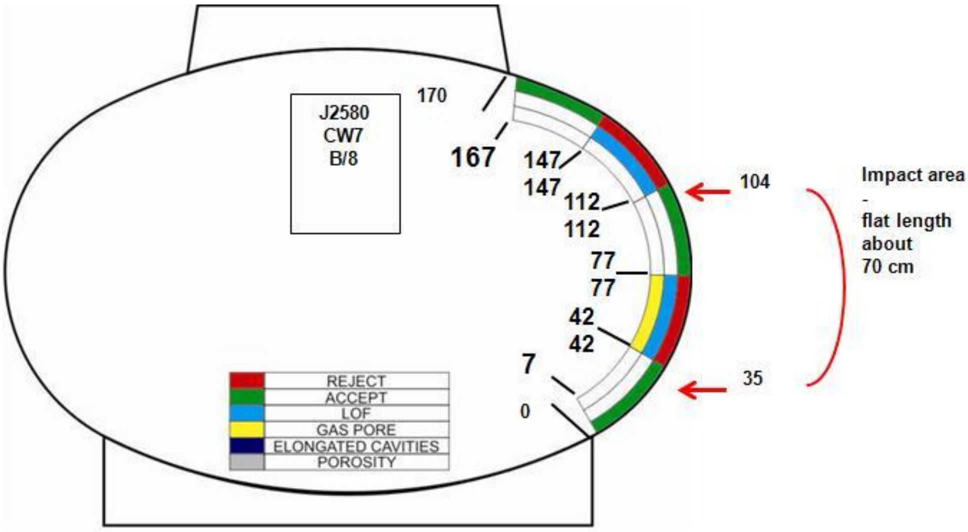
J2580	CW4(A)	10-45		Acc
J2580	CW4(A)	45-80	LOF 62 to 65 (intermittent)	Rej
J2580	CW4(A)	80-115		Acc
J2580	CW4(A)	115-150	LOF 144 to 149 (intermittent). Porosity @ 140 to 145.	Rej
J2580	CW4(A)	150-180	LOF 170 to 177cm	Rej



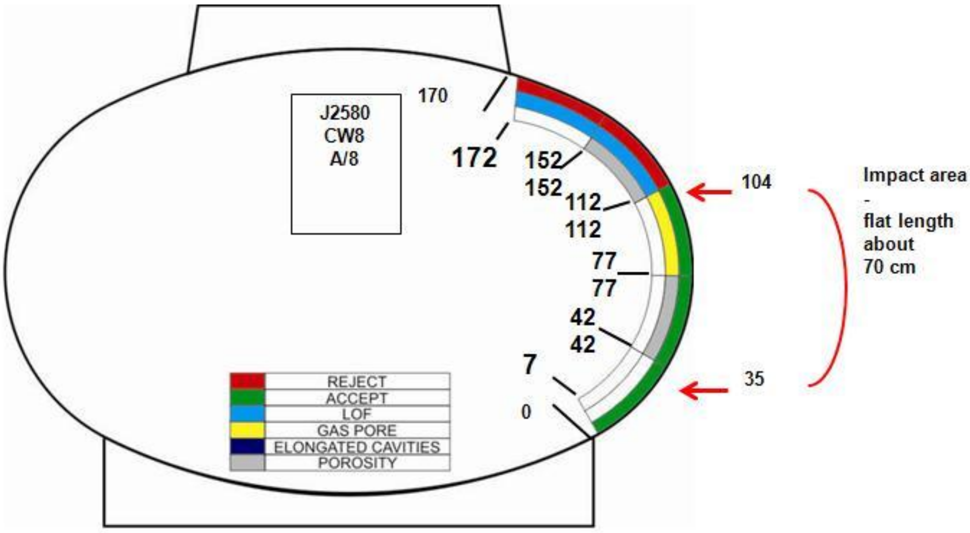
J2580	CW5(A)	0-45	Gas pore @ 34cm noted	Acc
J2580	CW5(A)	45-80	LOF 75 to 78cm	Rej
J2580	CW5(A)	80-115	Gas pores @ 87 to 90cm noted	Acc
J2580	CW5(A)	115-155	LOF 125 to 143cm	Rej
J2580	CW5(A)	155-170	Linear Porosity 181 to 183cm	Rej
J2580	CW5(A)	170-205	LOF 204 to 205cm. Porosity @ 200cm noted.	Rej



J2580	CW6(A)	0-35	LOF 20 & 25cm.Porosity in fillet noted.	Rej
J2580	CW6(A)	35-70	LOF 35 to 36, 40 to 55, 65 to 68cm.	Rej
J2580	CW6(A)	70-105	LOF 94 to 95cm.	Rej
J2580	CW6(A)	105-140	LOF 115 to 140cm	Rej

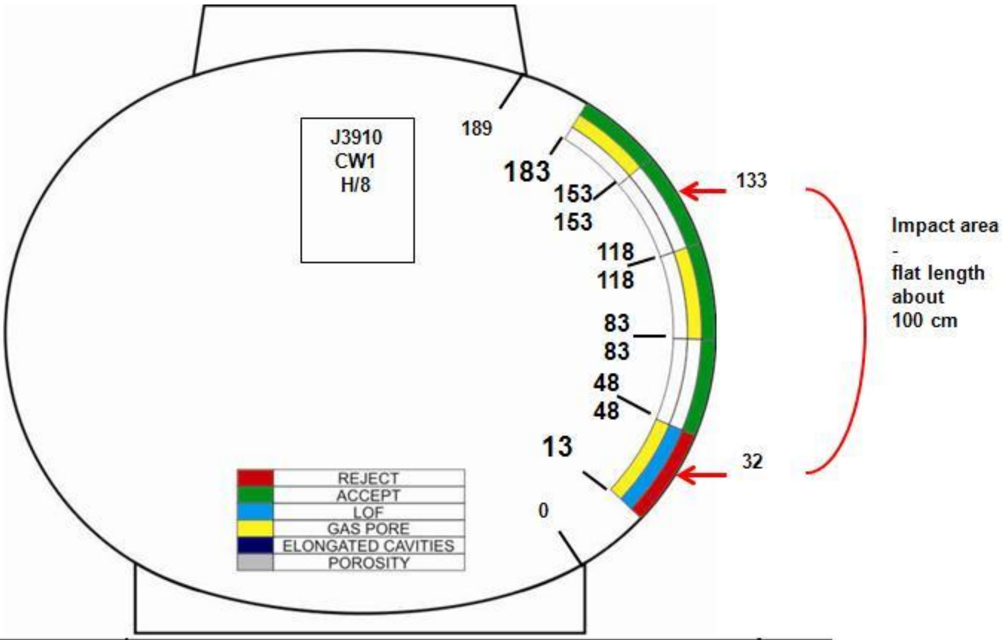


J2580	CW7(A)	0-35		Acc
J2580	CW7(A)	35-70	LOF 53 to 56cm (intermittent). Gas pore @ 60cm noted.	Rej
J2580	CW7(A)	70-105		Acc
J2580	CW7(A)	105-140	LOF 105 to 110cm, 117 to 119cm & 135 to 139cm.	Rej
J2580	CW7(A)	140-160		Acc

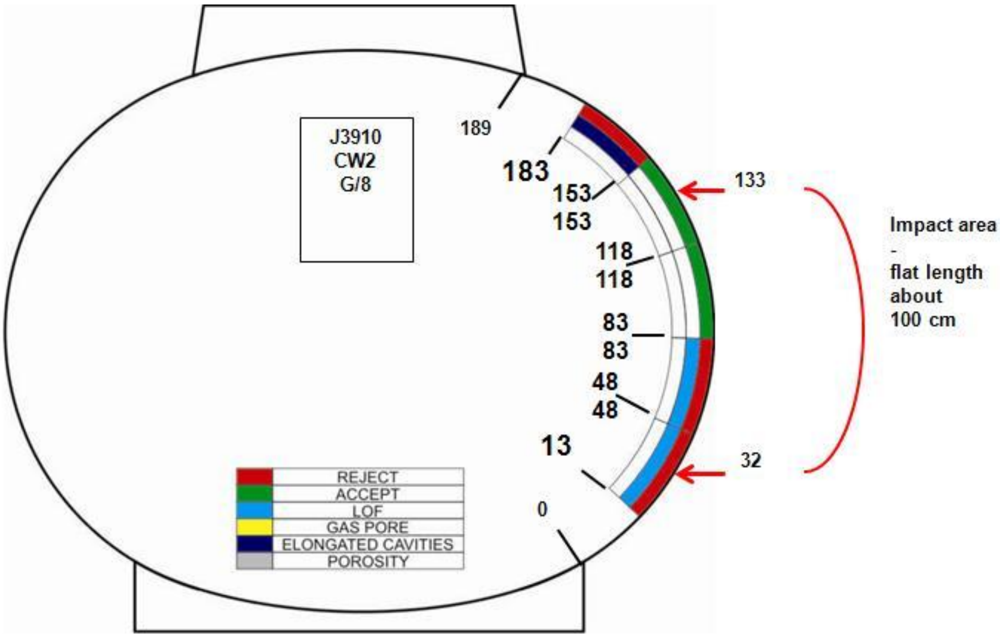


J2580	CW8(A)	0-35		Acc
J2580	CW8(A)	35-70	Porosity @ 64 to 66cm noted.	Acc
J2580	CW8(A)	70-105	Gas pore @ 97cm noted.	Acc
J2580	CW8(A)	105-145	LOF 130 to 131cm. Linear porosity @ 130 to 131cm, 138 to 140cm.	Rej
J2580	CW8(A)	145-165	LOF 155 to 165cm (intermittent)	Rej

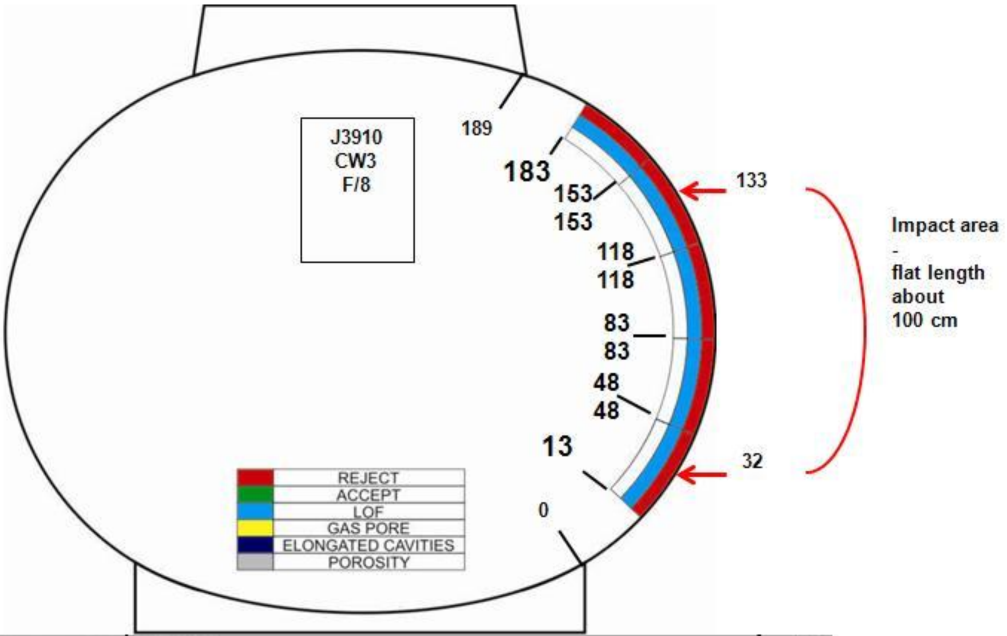
10.4.3 J3910 radiograph maps



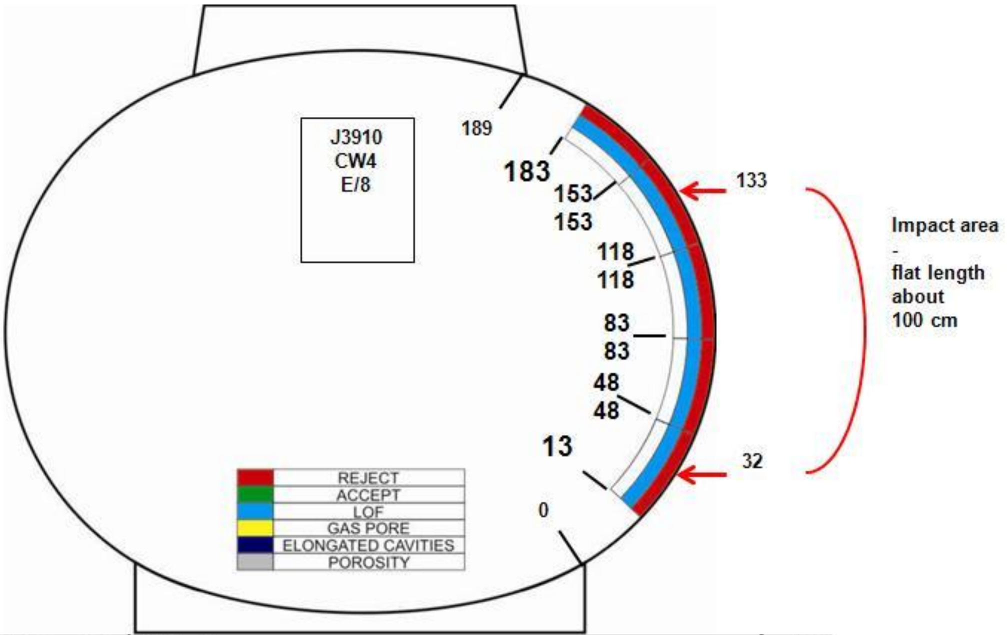
J3910	CW1(A)	0-35	LOF 0 to 2. Gas pore @ 20cm noted.	Rej
J3910	CW1(A)	35-70		Acc
J3910	CW1(A)	70-105	Gas pore @ 101cm noted.	Acc
J3910	CW1(A)	105-140		Acc
J3910	CW1(A)	140-170	Gas pore @ 160cm noted.	Acc



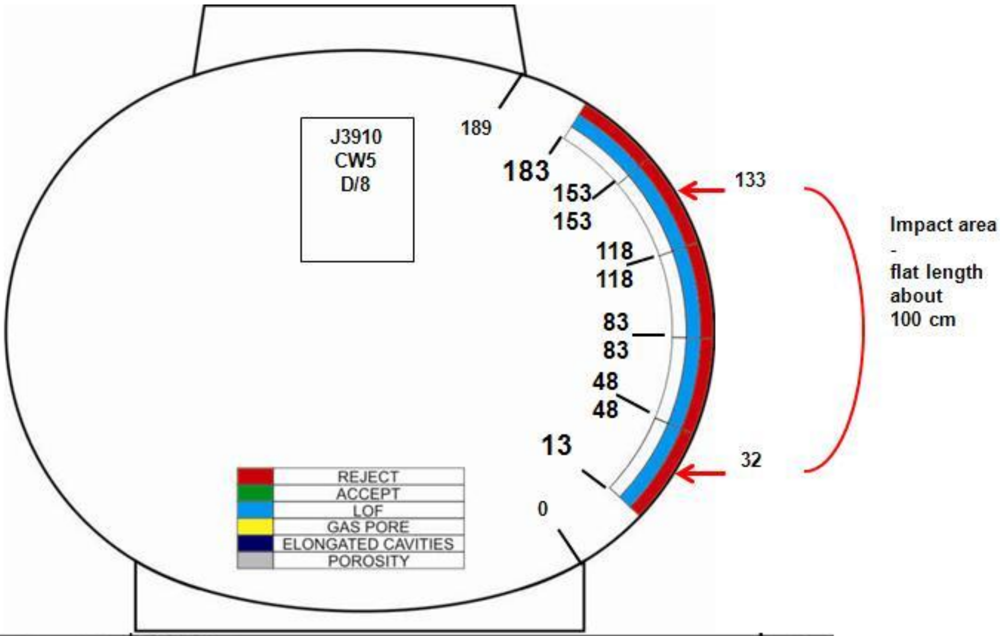
J3910	CW2(A)	0-35	LOF 7 to 10cm	Rej
J3910	CW2(A)	35-70	LOF 43 to 46cm	Rej
J3910	CW2(A)	70-105		Acc
J3910	CW2(A)	105-140		Acc
J3910	CW2(A)	140-170	Elongated cavities @ 163, 164, 169 to 170cm	Rej



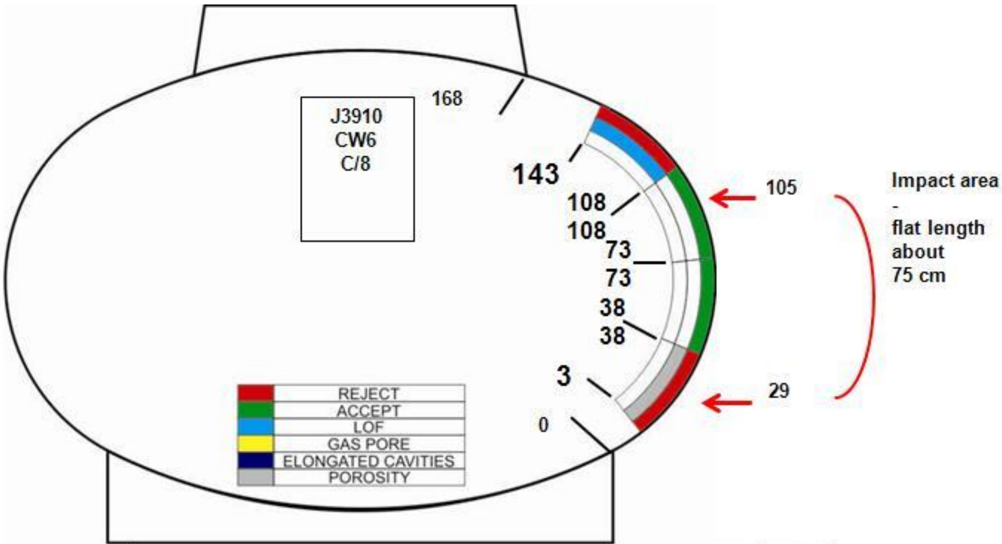
J3910	CW3(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW3(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW3(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW3(A)	105-140	LOF 105 to 140cm	Rej
J3910	CW3(A)	140-170	LOF 140 to 170cm	Rej



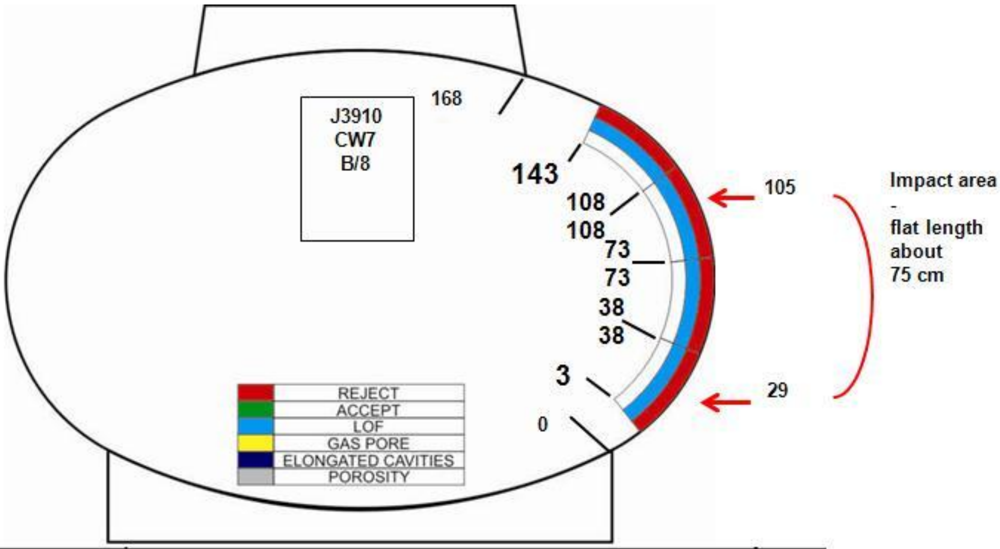
J3910	CW4(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW4(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW4(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW4(A)	105-140	LOF 105 to 140cm	Rej
J3910	CW4(A)	140-170	LOF 140 to 170cm	Rej



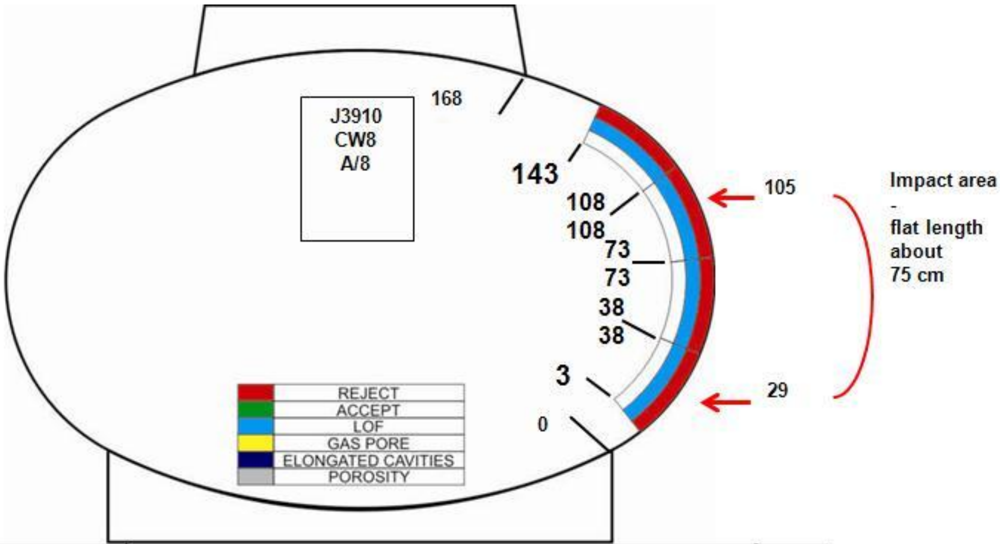
J3910	CW5(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW5(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW5(A)	70-105	LOF 70 to 90, 97 to 105cm	Rej
J3910	CW5(A)	105-140	LOF 105 to 140cm	Rej
J3910	CW5(A)	140-170	LOF 140 to 152cm	Rej



J3910	CW6(A)	0-35	Linear porosity 33 to 35cm	Rej
J3910	CW6(A)	35-70		Acc
J3910	CW6(A)	70-105		Acc
J3910	CW6(A)	105-140	LOF 116 to 119cm	Rej



J3910	CW7(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW7(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW7(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW7(A)	105-140	LOF 105 to 140cm	Rej



J3910	CW8(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW8(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW8(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW8(A)	105-140	LOF 105 to 120cm	Rej