Technical Audit Report On Behalf Of

Apache Energy Limited

M/V Western Trident

30th December 2004 to 10th January 2005

Verif-i Project Reference 04075

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Conclusion and Recommendations

The equipment is in a satisfactory condition for use on this survey. The equipment can be classified as follows:

Instrumentation:	Fair
Streamers:	Acceptable
Airgun Arrays:	Fair
Airgun Controller:	Fair

For clarification, Verif-i operates a four tier grading process. Equipment is defined as ‘Good’ if the auditor cannot find any faults or any areas of reduced performance; equipment is defined as ‘Fair’ if it requires only minor adjustments or modifications to be classified as ‘Good’. ‘Acceptable’ means meeting basic industry and contract specifications and ‘Unacceptable’ is defined as not meeting those same specifications.

The following recommendations are made to improve the performance and reliability of the equipment.

- Continue to substitute Guardian sections for ageing Sentry sections.
- Replace the two failing streamer sections at the first opportunity.
- Replace bad streamer depth controller and adjust ballasting where necessary at first opportunity.
- Continue to use the Omega analysis of daily and semi-monthly tests for streamer quality control, but ensure MSX results are checked in real time for anomalies.
- Monitor the performance of the nearfield hydrophone signals, ensuring that they are recorded to tape.
- Include a channel assignment for the nearfield hydrophones with the line logs.
- Adjust gun array depth ropes as necessary using depth indicator information.
- Check gun strings 7 and 8 for slight air leaks.

Summary

At the request of Apache Energy Limited, a technical audit was conducted on the instrument, source and receivers of the Western Geco vessel M/V Western Trident. The audit was conducted between the 30th December 2004 and 10th January 2005. The vessel was mobilising for a series of 3D surveys in the Gippsland Basin, off the south-east coast of Australia. The auditor was Colin Morris of Verif-i Limited.

The Trident had transited from Malaysia via Perth in Western Australia where some repair work had been done to a propeller bearing. The auditor joined the vessel in Portland, with the vessel en route to the Gippsland Basin. The seismic equipment was believed to be in good condition although a small number of streamer section changes were planned as part of routine maintenance.

The weather in the Bass Strait during streamer deployment and the audit was changeable, heavy seas contributing to a streamer tangle which cost 24 hours. Good use of the one available weather window allowed ballasting, bird replacement and adjustment of those streamers deployed using the workboat. Marginal weather after the streamer tangle restricted the crew to deploying one streamer at a time. A further deterioration in the weather caused a suspension of 36 hours in streamer deployment.

At the end of the audit a preliminary report was produced and discussed with the Party Chief, Chief Observer, Chief Navigator, Chief Mechanic and Chief Quality Assurance Supervisor (QAS). This report should be used in conjunction with this final report.

The instrument room on the vessel was adequate with acquisition and navigation in a horseshoe shaped console layout, set out across the boat. A large amount of floor space exists around the console area. Separate glass fronted offices for the crew management, Chief Observer and technician, and processing and QC were set up adjacent to the instrument room. The client's office was completely separate, along the passageway from the instrument room. There was also workspace in the two client QC cabins. The recording and navigation instruments together with the processing equipment were installed in another glass fronted room which provided a cooler environment than the general work area. The instrumentation was well laid out in a

series of racks allowing good access and cooling.

The vessel was purpose built in 1998/1999 and has adequate storage and working deck areas. Organization of this storage space has continued since the last audit conducted by Verif-i, and the deck areas are now clear and well laid out.

Key personnel onboard during the audit included:

RPS Hydrosearch Lead Rep	Jon Evan-Cook
RPS Hydrosearch Navigation Rep	Stephen Burt
Party Chief	Ian Halfpenny
Chief Observer	Victor Lopes
Chief Navigator	Paul Melody
Chief Gun Mechanic	Paul May
Chief QAS	John de Haai

General Recording Configuration

Recording system

Recording instrument	I/O MSX 24A
Number of streamers	8
Channels per streamer	384
Sample rate	2 ms
Record length	6.144 sec
Pre-amplifier gain	6 dB / 5.14 dB (Test / operate)
Low-cut filter	2 Hz / 12 dB octave
Anti-alias filter	206 Hz / 264 dB octave
Array forming	None
Recording media	IBM 3590B cartridge
Recording format	SEG-D Revision 1, 8058

Streamer

Streamer type	TUS Sentry and Guardian
Hydrophone type	TUS TS014
Group spacing	12.5 m interval
Channel number 1	Starboard outer, at head
Tailbuoy positioning	RGPS and acoustics
Bird spacing	19 per streamer

Airgun arrays

Number of source arrays	2
Total volume of each array	3,000 cubic inches
Number of strings per array	4
Type of airguns	I/O Sleeve
Spare guns on array	None
Positioning	Acoustics, RGPS

Airgun controller

Type	I/O Source Synchronizer System
Gun fire detect	Zero crossing

Recording Instrument

Data Acquisition System

The instrument was an I/O MSX 24A 24 bit recording system, running MRS version 2.0111, with a Continuous Recording System (CRS) running MSX version 4.1. This system provides a data management and buffering function.

The system was set up to record on four IBM Magstar 3590 B1A cartridge drives, which were assembled as part of a large robot driven tape cluster. A further 18 tape drives, assigned to data processing, and a 16 terabyte RAID assembly complete the cluster. Data is written to one tape drive and a copy immediately produced by the QAS department. The copy is then used for all QC purposes, thus verifying both cartridges. The data was recorded in SEG-D Revision 1, 8058 format.

There is an analogue low-cut filter at 2 Hz with a slope of 6 dB per octave applied automatically to the recorded data by the system. This system also applied a digital low cut filter at the same parameters, giving an overall low cut filter of 2 Hz at 12 dB per octave. An anti-alias filter of 206 Hz at 264 dB per octave was also applied.

Annotated SEG-D header Extended Header

Observer's Log – Instrument tests

Streamer

The vessel's MSX system was fitted with ten streamer interfaces, eight of which were in use for this survey. Up to sixteen auxiliaries can be recorded separately through an auxiliary interface box, while airgun array nearfield hydrophone data is sent directly from the airgun controller to the MSX Gun Signature Module. Pre-amplifier gain on the MSX is not user-selectable. A gain setting of 6 dB was used for testing, 5.14 dB for normal production. In-water electronics modules are installed between streamer sections, each electronics module digitises data from 16 streamer channels. Each streamer channel consists of a 14 hydrophone centre weighted array 17.55 metres long, giving overlapping groups with a spacing of 12.5 metres. The hydrophone signals are filtered and digitised in the electronics module and sent to the recording instrument by telemetry. Each module also contains an oscillator for recording tests and a clock synchronised to the master clock onboard.

Recording System Tests

A complete set of instrument tests was recorded. Due to adverse weather conditions instrument tests were performed with the streamers at a depth of 17 metres, thus negating most effects caused by swell and wave action. Due to a networking problem later resolved by the crew, print outs of the results of the MSX instrument tests were not available. On screen results from the MSX Event Visualisation Processor were viewed, although some of the test results are more difficult to interpret. Because of this the crew chose to use the onboard processing Omega system’s instrument test facility as their main quality control for daily and semi-monthly tests. The results from the Omega analysis were checked against those produced by Verif-i’s proprietary software, Testif-i, and a good correlation was found between the two sets of results.

Instrument test data was input into Testif-i on the vessel by reading the data from the original 3590 tapes on the vessel’s processing system and sending it via the network onto the hard disk of the auditor’s PC.

Noise and Offset

The purpose of this test is to measure the amplitude of the noise signal and D.C. offset generated by the recording instrument. During acquisition of seismic data these signals are added to the hydrophone signals causing degradation of the seismic data. The amplitudes of the noise and offset signals are influenced by factors such as the pre-amplifier gain and the system bandwidth (i.e. filter settings) so there are different specifications for different instrument settings.

The test is performed by disconnecting the receiver input to the system and applying a terminating resistor to the pre-amplifier input. In this state there would, ideally, be no signal recorded by the acquisition instrument as there is no input signal. Any signal recorded is attributed to system noise, for A.C. signals, or offset, for D.C. ones.

In order to simulate a zero voltage a 50/50 bit pattern is sent to the modules during this test.

Results

All channels passed the MSX specification of 2.9 microvolts. I/O do not quote a specification for offset but a figure equivalent to that for internal noise has been applied for this analysis.

[Plot of Noise Test]

Filter Pulse

The high-cut filter is a digital filter using decimation of an oversampled signal to produce very accurate and steep filters. Each channel has a fixed low-cut filter with corner frequency of 2 Hz and slope of 6 dB per octave. There is also a switchable digital low cut filter in steps of 2 Hz, also with a slope selectable in steps of 6 dB per octave.

This test checks the accuracy of the recording filters used on each seismic channel. Inaccuracies in the recording filters would affect the frequency response of the channel. There are a number of parameters that can be measured for a filter such as phase and amplitude similarity and pass band corner frequencies.

The channel inputs are terminated with simulated receivers across which a pulse signal is generated. A pulse signal contains a wide spectrum of frequencies that enables the filter response to be analysed across the full instrument bandwidth.

Results

The analysis of the impulse test calculated the following average filter frequencies:

	Frequency
-3 dB low-cut	2.8 Hz
0 dB mid-band	16.8 Hz
-6 dB high-cut	210.0 Hz

All channels passed a 7 % amplitude specification. There is no quoted specification for phase response, but a nominal figure of 7 degrees was imposed. The effect of the filter was confirmed as zero phase.

Plot of amplitude results   Plot of phase results

Distortion

This test is used to determine the amount of distortion the recording system adds to the recorded seismic signals. Distortion of a signal will introduce harmonics of the signal not present in the original data. The amount of distortion will depend on the frequency and amplitude of the input signal. As distortion is generated at multiples of the fundamental frequency it follows that the distortion of high frequency signals will occur above the high-cut filter frequency. For this reason lower frequency signals are to be preferred for assessment of distortion.

The recording channel inputs are terminated with simulated receivers and a sine wave signal imposed on them. The frequency and amplitude of the fundamental signal and a number of harmonics are calculated.

Results

All channels passed the specification of 0.0005 % for full-scale input signal.

Distortion Summary

Distortion Full Scale
Distortion FS -10 dB
Distortion FS -20 dB
Distortion FS -30 dB
Distortion FS -40 dB
Distortion FS -50 dB
Distortion FS -60 dB
Distortion FS -70 dB
Distortion FS -80 dB
Distortion FS -90 dB
Distortion FS -100 dB

Dynamic Range

The dynamic range of a system is the ratio of the smallest signal that can be resolved by the system to the largest signal that can be accurately recorded by it. “Global” or “Total” dynamic range is a misleading figure quoted by some manufacturers whereby the system settings are changed between measurement of the two amplitudes. A more meaningful figure is the “Instantaneous” dynamic range in which both amplitude measurements are made with identical system settings.

The specification for dynamic range with the MSX is that the internal noise of the system should be more than 114 dB below a nominal full scale signal of 1448 mV. Testif-i was used to compare the appropriate distortion file with the internal noise file to produce a figure for time domain dynamic range. In addition Testif-i analysis in the frequency domain includes the recorded harmonics giving a clear picture of the instantaneous dynamic range. The results are included here for information only.

Results

One channel, channel 120 on streamer 4, was seen to marginally fail the 114 dB specification.

Time domain analysis DRD failure

A nominal specification of 100 dB was applied to the results for frequency domain dynamic range. All channels passed this nominal specification, this is considered good.

Frequency domain analysis

Crossfeed Isolation

The crossfeed between adjacent channels is calculated as a decibel ratio between the R.M.S. levels of the signal on a driven and an adjacent undriven channel. The undriven channels are normally terminated with resistors inside the module. A second record is made with the positions of the driven and undriven channels reversed. These two records together represent a crossfeed test for the module unit.

The MSX crossfeed test is unique in the way it performs the test. A full scale signal is applied in Common Mode to the inputs of pairs of adjacent channels i.e. channels 1 and 2 are driven, while channels 3 and 4 are undriven etc. The pairs are then switched for the second test. The receivers are connected during this test, and because of this there is a risk of noise contaminating the results.

Due to the switching and gain of the amplifiers the common mode driving signal when set to 0 dB in the test signal control is 4 dB higher than the normal differential signal. The I/O specification is quoted as 60 dB down from input signal, and it is therefore noted that this equates to 56 dB down from normal system full scale. This is the method used by the crew on the Western Trident.

An alternative method is to enter a driving signal level 4 dB above the differential full scale signal. This gives a theoretical common mode signal of 2295 mV which was used for the Testif-i analysis. The MSX uses a specification of 2295 μV, which is 60 dB below the 2.295 Volt input, confirming the value for input signal level.

Results

The MSX results include driven channels and it is left to the observer to identify the undriven channels under test from the list produced. This is considered difficult to do when viewing the results on the instrument display and the results would need to be printed out and manually sorted to determine test failures.

The Omega analysis for the same test was scrutinized and shown to agree exactly with Testif-i analysis of the data. It was concluded that the Omega analysis produces an accurate representation of the instrument crossfeed.

Crossfeed summary Crossfeed failures

Odd channels driven Even channels driven

This test is recorded with hydrophones connected so the results include noise picked up by the hydrophones. As well as recording the streamer tests at a depth of 17 metres to negate swell effects, the effects caused by noise were mitigated by using frequency domain calculations so that all noise not at the driving signal frequency is ignored.

A total of 54 channels failed the specification, all within Sentry sections. I/O state that the specification should only be applied to new sections, thus bearing out the results of this test. Whilst accepting that valid data will be recorded by channels with crossfeed results marginally outside the specification, it is felt that the results reflect the condition and the age of the streamers.

It is considered that channels 161 to 163 and channel 165 on streamer 4 together with channels 376 to 384 on streamer 8 would be severely impacted by crossfeed and should be changed by the crew at the first opportunity. It is also recommended that WesternGeco continue to replace the ageing Sentry sections with new Guardian sections in order to improve the crossfeed statistics for the spread.

Common Mode Rejection Ratio

Common mode signals are those which appear equally at both input terminals to an amplifier, in a seismic environment these are typically caused by an unbalanced input into the pre-amplifier. Ideally the common mode signals will be attenuated by the amplifier and will not appear at the output.

Common mode rejection is measured by driving both inputs of each pre-amplifier with a common mode sine wave signal. The common mode rejection ratio is then the ratio between the level of the driving signal to the level of the signal recorded by each channel.

Similarly to the Crossfeed test, I/O quote the specification relative to the level of the common mode input signal which is 4 dB greater than normal full scale. The specification of 70 dB down from the common mode signal is equivalent to a specification of 66 dB down from the normal system full scale. This is the method used by the crew on the Western Trident.

It is again possible to take the quoted allowable signal amplitude of 725 μV and scale it by the specified 70 dB to find the theoretical amplitude of the input signal used in this test. In this case the amplitude is calculated as 2293 mV and this figure has been used in the Testif-i analysis with the quoted 70 dB specification.

Results

Channel 91 on streamer 2 marginally failed this test, all other channels passed this specification.

Plot of CMRR results CMRR failure

Hydrophone Gain Accuracy

This test measures the amplitude matching of the different channels. For a given input signal all channels should record an identical amplitude on tape. This test checks that the amplitude of the input signal is correctly measured by all channels. The specification will depend on a number of parameters, notably the amplitude and frequency of the test signal. The frequency used is normally near the middle of the filter pass-band, to reduce the effect of the filters on the result, and of an amplitude at or near full-scale, to reduce the effect of noise.

A 15.625 Hz full-scale signal is connected to the input of each recording channel. The amplitude of the signal reported by each channel is then calculated and compared with the average recorded signal. Any channels which deviate from the average by more than the specified amount fail the test.

With the I/O MSX, this test is performed with the hydrophones connected, providing an overall accuracy representation for the complete recording channel. I/O quote a specification of 4 % for new streamers, but this is generally regarded as impractical as it makes no allowances for the ageing of the hydrophones and ambient noise pickup. I/O also quote a specification of 4 % for channel amplitude matching without the hydrophones connected. This is considered to be a loose specification for modern electronics. WesternGeco have chosen to use this specification and have allowed a further 6 % error for variations in hydrophone group capacitance as described in a technical note from the streamer manufacturer, giving an overall specification of ±10 % for the test.

As the hydrophones are connected for this test, there is a possibility that noise will contaminate the results so WesternGeco use these results as a performance guideline rather than a pass / fail standard. This method has been assumed for the purposes of the audit, although with the streamers at 17 metres, noise effects were minimised.

Results

Gain accuracy results   Gain accuracy failures

A total of 21 channels failed the 10 % specification, of which 9 were included on two sections marked for replacement by the crew.

Hydrophone Impulse Test

In this test a pulse is applied to the receiver groups which are connected to the inputs to the channels in the modules. Any leakage in the streamer or faulty hydrophones will affect the amplitude of the pulse, decreasing or increasing it.

As the receivers are connected for this test it is likely that there is noise contaminating the test. For this reason the tests were recorded with the low cut filter set to 8 Hz with a slope of 18 dB filter to reduce the amount of low frequency noise contaminating the test.

Results

Testif-i analysis was used to mimic the Omega analysis, processing the data on a streamer-by-streamer basis.

Streamer 1	Failures	Streamer 2	Failures
Streamer 3	Failures	Streamer 4	Failures
Streamer 5	Failures	Streamer 6	Failures
Streamer 7	Failures	Streamer 8	Failures

Of the 43 channels failing the 7 % specification, 23 were marginal failures. Of the remaining 20 channels, ten are included in the two sections marked for removal. These 20 channels show good correlation with the channels failing the Hydrophone Gain Accuracy test above.

Hydrophone Step Test

In this test the MSX applies a voltage step to the streamer channels and records the response of each channel. Any leakage or crossfeed will affect the response of the hydrophones. Results for this test should be similar to those produced by the Hydrophone Impulse Test above, although a greater number of marginal failures are produced. This is considered to be due to this test being more susceptible to noise effects and should therefore be used to support the Impulse test results rather than a definitive list of bad channels.

Testif-i analysis was again produced on a streamer-by-streamer basis. Results were shown to match the Omega analysis.

Streamer 1	Failures	Streamer 2	Failures
Streamer 3	Failures	Streamer 4	Failures
Streamer 5	Failures	Streamer 6	Failures
Streamer 7	Failures	Streamer 8	Failures

Auxiliary Channels

The auxiliary channels on the MSX are recorded in two ways. 16 external signals may be connected to an auxiliary module connected directly to the instrument. Each of these channels is defined as a separate channel set in the SEG-D header. In addition there are 64 channels available for gun signature data recorded by the Continuous Recording System, using information passed from the source controller via the Spectra navigation system.

The 64 channels of gun signature data are allocated as 8 channels per gun string. As there are six near field hydrophones per gun string, there are two spare channels. This allows the crew to compensate for bad pre-amplifier channels in the analogue to digital converter module at the front of the string by using the spare channels, however this leads to different channel allocations between gun strings.

As the gun signature data may be used for source analysis when processing this data, it is important that a channel configuration listing be included with each dataset.

The auxiliary channel configuration for the first 7 sequences is defined here.

Plotters

There were two Oyo Geospace GS624-2 plotters in use in the Instrument Room, one for MSX playback of the production data, one for use by the Quality Assurance department. The plotter connected to the MSX was seen to display good quality SEG polarity plots.

Recording Polarity

Polarity was assessed on the first breaks from a production file analysed in Testif-i. An increase in pressure at the hydrophone should produce negative numbers on tape. This is evidenced by the downward break on the Testif-i plot of the first breaks on several channels. This shows SEG standard polarity.

Polarity Plot

In contrast it was noted from airgun test files that the nearfield hydrophones signals are recorded with non-SEG polarity.

Nearfield Hydrophone Polarity Plot

System Clock Accuracy

Clock accuracy specification: Not specified

It is important in any recording system to ensure that the master clock, which controls the timing of all major functions, is running to its specified accuracy. A clock running at the wrong speed would cause sampling intervals to be in error, and the consequent seismic event timing errors could lead to processing problems.

The clock signal was recorded on an auxiliary channel and a 20 second record taken. Testif-i analysis gave a value of 3.2 ppm slow, which compares with figures of 2.7 ppm in September 2004 and 1.5 ppm slow in February 2004.

System Clock Analysis

Although the clock can be seen to drifting gradually with time, these current values will not present problems at the parameters used during this survey. It is recommended however, that, at an operationally convenient time, a precision frequency meter be used to monitor the system master clock, and this should be adjusted as necessary.

Streamers

Each streamer consisted mainly of Thales Sentry sections with a number of Guardian sections at the front end of each. The Thales Sentry sections predominantly date from 1999 and 2000. The Guardian sections are new units dating from 2003 and 2004. In addition a new version of Guardian sections with better impact noise tolerance was deployed at the heads of streamers 3 and 6. Examination of the specifications for each type of streamer showed that the same hydrophone type is used in both, with the same group layout and identical group sensitivity. There is a difference of 7 nF in the group capacitance (Sentry 273 nF, Guardian 280 nF), but the tolerance for this is ±14 nF, so it is concluded that the two streamer types are electrically compatible.

Outside streamers have greater quantities of Guardian sections reflecting their superior performance and greater reliability. The number of channels of Guardian section on each streamer was as follows:

Streamer 1	160 channels
Streamer 2	112 channels
Streamer 3	96 channels
Streamer 4	96 channels
Streamer 5	96 channels
Streamer 6	96 channels
Streamer 7	96 channels
Streamer 8	144 channels

At full deployment streamer tests were performed and with the airgun arrays in the water the crew ran noise tests to show system performance with this configuration. Noise characteristics were found to be generally the same for all streamers.

The physical condition of the streamer sections was good. Fairing on the cross tag lines was seen to be good, and also on the new Lightweight Optical Lead-ins used for the four outer streamers, and adequate on the lead-ins used for the inner four streamers. It was also noted that no stretch sections were used on any streamers.

Digicourse 5011 Compass Birds

Examination of the test equipment in the bird shack showed that the Druck DPI603 manometer, serial number 4529, used for testing depth readings on the birds had been calibrated when new on the 21st September 2004. This unit was used to apply pressures equivalent to 8 metres and 10 metres of depth to a selection of compass birds.

Results were as follows:

Serial Number (Streamer and bird position)	No pressure applied	11.68 psi (equiv 8 metres)	14.6 psi (equiv 10 metres)
	Reading	Reading	Reading
15575 (S3B17)	0.1 metre	8.1 metre	10.1 metre
9211 (S2B1)	0.0 metre	8.2 metre	9.9 metre
17016 (S4B3)	0.0 metre	8.0 metre	10.1 metre
16438 (S6B2)	0.1 metre	7.9 metre	9.9 metre
14581 (S5B6)	0.0 metre	7.8 metre	9.8 metre
12810 (S7B5)	0.0 metre	7.9 metre	9.8 metre
26177 (S7B4)	0.0 metre	8.0 metre	10.1 metre

As shown, the indicated depths were correct to within 20 centimetres, which is considered acceptable.

The crew use in-house software, Geco Diagnostic for Digicourse Birds, version 3.1, to test the 5011 compass birds. The test station was shown to be working correctly, testing depth indication, wing motor, compass bias and battery voltage.

It was noted that bird 12810 had a bad wing motor, otherwise all birds showed correct performance.

Group Capacitance

The capacitance of the two versions of Guardian streamers was checked to show compatibility of the improved impact noise response design with the original design.

Original design		Improved design	
Section 6079		Section 6320	
Pair	**Reading**	**Pair**	**Reading**
1	253	1	269
2	269	2	257
3	243	3	269
4	272	4	267
5	270	5	268
6	267	6	269
7	253	7	268
8 high	132	8 high	132
8 low	138	8 low	137

Note that group 8 is a split group with each half forming a complete group with the equivalent channel on the adjacent section.

Group capacitance is specified as 273 nF at 22^{o}C, with a temperature variation of 1.4 nF per degree Celsius. It can be seen that, with the exception of channel 3 on section 6079, the channels on these sections show a better than 6 % variation from the nominal value of 270 nF when measured at a temperature of 20^{o}C.

It was noted that channel 3 on section 6079 had one bad hydrophone.

Group Sensitivity

In-water analysis of streamer sensitivity is not definitive as there is a possibility of noise contaminating the results. The shallower the operating depth, the noisier the data tends to become. The effects are exacerbated in seas with a heavy swell and conditions such as those experienced during the early sequences recorded.

A sample of 20 consecutive shots was taken from each production sequence. Testif-i analysis was used to average channel amplitudes over the shots and these average amplitudes were then compared with other channels with similar offsets from the front of the streamer.

Applying the contract specification of 3.0 dB (40 %) to the data recorded on sequence 7, the latest recorded before the auditor left the vessel, a total of 21 channels appear to fail. Due to the statistical nature of the analysis thirteen of these channels can be disregarded due to gross single channel errors distorting the signal amplitude at a specific offset. Of the remaining eight channels, five appear to be due to depth anomalies which the crew will address with depth controller changes and ballasting adjustments using the workboat at the first opportunity. Two of the others are bad channels noted on other tests, the last is a noisy channel.

Streamer RMS Failures at 3 dB

In the streamer repair workshop, the TMS Automatic Test Equipment Sensitivity Test Software version 2.0 was being run with a tolerance of ±1.5 dB (18.8 %). This tolerance is industry standard, and is well within the contract specification of 3 dB (40 %).

Airgun Controller

The vessel was equipped with an I/O Source Synchronizer System (SSS) gun controller running OCM version 1.8 software. This system receives a computed closure for the next shot from the navigation system. It then fires the guns and provides a timebreak for the recording system. This vessel has integrated two navigation systems, WesternGeco's proprietary TriNav system running software version 2.6.0 (Patch 26) and a Concept Systems Spectra unit running software version 9.8.04. The Spectra system is used as a source selection tool, toggling between the port and starboard arrays and the TriNav is used for all other navigation functions.

Investigation of the system timing showed that the start signal to the SSS system is issued by the Trinav 604 ms before the aimpoint. The signal is also sent to the TrueTime system to timestamp the navigation data and the external header. TriNav then issues a Recording Start signal to the MSX 328 milliseconds before the aimpoint, allowing the instrument to align tape drives. A Fire Command signal is then sent by TriNav to the SSS 128 milliseconds before the aimpoint. The SSS system delay is set to 128 milliseconds, thus causing the guns to be fired at the aimpoint. At the Aimpoint the SSS registers when 62.5 % of the volume of the array has fired and then sends a signal TBA1 to Spectra, which in turn sends a Timebreak to the MSX, starting the record. It also sends a timing pulse to the TrueTime system to timestamp the time of the shot. Note that the two timestamps should occur 604 milliseconds apart although some variation is to be expected. A 40 millisecond MSX timebreak window was used to allow for this variation.

System timing diagram Timing Data Flow

The crew had seen problems with this system on previous contracts when the two independent navigation systems lost synchronisation causing occasional shotpoints to be missed, or alternatively for the same source to shoot consecutive shotpoints. To address both of the above problems the Spectra offset to the first CMP had been reduced by 3 metres to allow the Spectra cycle to start earlier than the Trinav.

Displays on the SSS are generally good, although it was noted that automatic monitoring of the nearfield hydrophones is difficult. System memory is limited, thus the more QC windows that are opened, the greater the risk of the system crashing. Nearfield hydrophone monitoring is not permanently enabled by the crew in order to limit the number of windows in use.

The parameters of the SSS were examined and were found to be acceptable. It was noted that the SSS does not compensate for the offset from the guns to the Depth Indicators so that the reported depth is that of the Depth Indicators rather than the guns. The offset to the guns is noted on the observer's log and this depth should be added to the readings from the gun indicators to give the actual gun depth.

Airgun Arrays

The dual arrays were made up of the following:

Airgun type	Sleeve
Total volume of each array	3,000 cubic inch
Number of strings / array	4
Number of active guns per array	32
Number of spare guns per array	0
Number of near-field hydrophones	48 (24 per array)
Number of depth sensors	3 at gun positions 1, 4 and 6
Working air pressure	2,000 psi (nominal)

Each 3,000 cubic inch array consisted of four strings of eight Sleeve airguns all of which were active, giving a total of 32 guns per array. The float system consisted of a front aluminium pod with a 400 mm pressurized tube running the length of the gun strings. The guns were suspended by chains hung from gun plates which formed a framework around the manifold pipe. The manifold pipe and framework in turn were suspended from the floats by individual ropes at the gun positions.

Measurements were taken and the array geometry was found to be correct. Chain lengths were found to be good and the in-line distances between guns were found to be within 10 centimetres of design positions.

Nominal depths were measured although new ropes had been fitted and stretching was anticipated. The crew intended adjusting depth ropes from depth indicator information once the strings had been deployed. Click tests were conducted to show correct connection of each gun to the gun controller.

Gun Array Gun measurements

Three depth transducers per sub-array were attached to the manifold in the indicated positions. Air pressure sensors were mounted at gun position 5 on each sub-array. As each gun has a separate pressure line taken from the manifold this should give an accurate reflection of the pressure for each gun. Each sub-array had an RGPS unit and acoustic units mounted as indicated in the gun array diagram.

The depth transducers were checked using the calibrated manometer to show correct operation. Readings were taken at zero and at a pressure of 7.3 psi, equivalent to a depth of 5 metres. The crew had changed five units in pre-audit tests, a further three gave incorrect readings during the audit and were replaced. The final results were as follows:

DI Position	Zero pressure	Equiv 5 metre	DI Position	Zero pressure	Equiv 5 metre
S1 D1	-0.1 m	5.0 m	S5 D1	0.0 m	5.1 m
S1 D2	0.1 m	5.2 m	S5 D2	0.0 m	5.0 m
S1 D3	-0.2 m	4.9 m	S5 D3	-0.1 m	4.9 m
S2 D1	0.1 m	5.0 m	S6 D1	0.1 m	5.0 m
S2 D2	-0.1 m	5.0 m	S6 D2	0.0 m	4.8 m
S2 D3	-0.1 m	5.0 m	S6 D3	0.0 m	4.8 m
S3 D1	-0.1 m	4.8 m	S7 D1	0.1 m	5.0 m
S3 D2	-0.1 m	5.0 m	S7 D2	-0.1 m	4.9 m
S3 D3	0.1 m	5.2 m	S7 D3	-0.1 m	4.9 m
S4 D1	0.0 m	5.0 m	S8 D1	0.1 m	4.9 m
S4 D2	0.0 m	4.8 m	S8 D2	-0.1 m	5.1 m
S4 D3	-0.2 m	5.2 m	S8 D3	-0.1 m	4.8 m

Results show that all Depth Indicators currently in use were accurate to within 20 centimetres. This is considered acceptable.

Pressure drop tests were performed as part of the crew's maintenance regime. During the audit, a pressure drop test over 10 minutes at the operating pressure of 2000 psi showed that strings 7 and 8 had slight leaks resulting in a loss of pressure greater than 100 psi. For string 7 this was found to be 130 psi, string 8 was 120 psi. Although not currently creating a problem, these strings should be investigated as a priority when planning maintenance of the strings. Pressure drop tests after each line are recommended together with monitoring of the nearfield hydrophone signals during production as these can also show small leaks.

Nearfield hydrophone signals are recorded at each gun or cluster position, with the analogue signals being converted to digital data by an in-water unit at the front of each string. Eight channels are available for each string giving two spare channels for use in the event of signal degradation within the recording system however, if this is done, the strings will have non-standard configurations. This is currently the case with strings 6 and 7.

A fault occurred during early production sequences such that, although the nearfield hydrophone signals from gun string 6 appeared to be correct from SSS displays, the signals were not being recorded to tape. This was under investigation by the crew although re-setting the MSX GSM appeared to resolve the issue. A quality control should be in place to verify that the nearfield hydrophone signals are recorded to tape.

Bubble period tests were recorded for each individual gun to establish gun size and stability. Results were good, the graph showing acceptable linearity of response as the volume increases. The bubble period of each gun is affected by the depth at which the shot is taken. The slight variations in period for the 80 and 150 cubic inch guns are a function of the 'over-under' cluster design.

Measured bubble periods

Observer's Log – Strings 1 and 2 | Observer's Log – Strings 3 and 4

Observer's Log – Strings 5 and 6 | Observer's Log – Strings 7 and 8

Presented here are Testif-i analysis plots for each gun. Strings 1 to 4 are the starboard source and the plots for both arrays are laid out to reflect the position within the array.

4-1 Plot	4-1 Stats	3-1 Plot	3-1 Stats	2-1 Plot	2-1 Stats	1-1 Plot	1-1 Stats
4-2 Plot	4-2 Stats	3-2 Plot	3-2 Stats	2-2 Plot	2-2 Stats	1-2 Plot	1-2 Stats
4-3 Plot	4-3 Stats	3-3 Plot	3-3 Stats	2-3 Plot	2-3 Stats	1-3 Plot	1-3 Stats
4-4 Plot	4-4 Stats	3-4 Plot	3-4 Stats	2-4 Plot	2-4 Stats	1-4 Plot	1-4 Stats
4-5 Plot	4-5 Stats	3-5 Plot	3-5 Stats	2-5 Plot	2-5 Stats	1-5 Plot	1-5 Stats
4-6 Plot	4-6 Stats	3-6 Plot	3-6 Stats	2-6 Plot	2-6 Stats	1-6 Plot	1-6 Stats
4-7 Plot	4-7 Stats	3-7 Plot	3-7 Stats	2-7 Plot	2-7 Stats	1-7 Plot	1-7 Stats
4-8 Plot	4-8 Stats	3-8 Plot	3-8 Stats	2-8 Plot	2-8 Stats	1-8 Plot	1-8 Stats

8-1 Plot	8-1 Stats	7-1 Plot	7-1 Stats	6-1 Plot	6-1 Stats	5-1 Plot	5-1 Stats
8-2 Plot	8-2 Stats	7-2 Plot	7-2 Stats	6-2 Plot	6-2 Stats	5-2 Plot	5-2 Stats
8-3 Plot	8-3 Stats	7-3 Plot	7-3 Stats	6-3 Plot	6-3 Stats	5-3 Plot	5-3 Stats
8-4 Plot	8-4 Stats	7-4 Plot	7-4 Stats	6-4 Plot	6-4 Stats	5-4 Plot	5-4 Stats
8-5 Plot	8-5 Stats	7-5 Plot	7-5 Stats	6-5 Plot	6-5 Stats	5-5 Plot	5-5 Stats
8-6 Plot	8-6 Stats	7-6 Plot	7-6 Stats	6-6 Plot	6-6 Stats	5-6 Plot	5-6 Stats
8-7 Plot	8-7 Stats	7-7 Plot	7-7 Stats	6-7 Plot	6-7 Stats	5-7 Plot	5-7 Stats
8-8 Plot	8-8 Stats	7-8 Plot	7-8 Stats	6-8 Plot	6-8 Stats	5-8 Plot	5-8 Stats

A comparison between the port and starboard array was made using the frequency response of streamer data recorded during sequence 4. The response showed acceptable similarity with most variation in frequencies above 200 Hz.

Source comparison

Airgun reliability and performance was measured by taking a 20 consecutive shot sample from each production sequence. The amplitude of each nearfield hydrophone channel was averaged over 20 shots from sequence 1 and the deviation from the averages shown here. All channels show less than 10 % deviation from the mean. Note that four of the unused channels also show signals comparable to those with nearfield hydrophones connected. These signals are due to crossfeed and to noise picked up by the unterminated channels

Airgun similarity

There were three LMF 57/138, 2000 cfm and one LMF V17/5518, 75 cfm compressor onboard. The smaller compressor is used offline, each of the 2000 cfm compressors is individually capable of supplying both gun arrays using the production parameters. Pressure control during the gun tests and early production sequences was found to be good.

Health, Safety and the Environment

A practical approach to HSE was evident throughout the audit. Back deck operations were seen to be conducted in a controlled fashion.

A full tour of the vessel was given shortly after joining in Portland. An abandon ship drill was conducted on the 9th January.

Crew Competence

The crew showed good knowledge of their positions and work practices during the audit, although two observers were new to the vessel.

Good quality control was shown during deployment and testing of the guns and streamers was conducted efficiently. Equipment problems were quickly investigated and resolved. All requests from the auditor were dealt with promptly.