BRUCE ACKLAND & ASSOCIATES PTY LTD
CORROSION AND CATHODIC PROTECTION CONSULTANTS
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OPINION REGARDING IN LINE INSPECTION AND ALTERNATIVE METHODS FOR DETECTING METAL LOSS IN PIPELINES

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CLIENT: APA GROUP

Attention: **Mr Anthony Jones**
Mr Alan Bryson

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EXECUTIVE SUMMARY

In Line Inspection (ILI) involves the insertion and propulsion of a device carrying a variety of test equipment, commonly referred to as an "intelligent pig", within a pipeline. The ILI method offers the only way to positively identify all external metal loss in pipelines due to corrosion.

Exploratory excavations and visual examinations without proof of metal loss are impractical and generally prohibitively expensive where the pipeline passes through protective casings, under major roadways or at otherwise inaccessible locations. ILI also eliminates the need for excessive numbers of excavations at locations where multiple coating defects have been identified by other methods.

It is therefore considered good engineering and economic practice to install ILI facilities on pipelines which are considered important but which do not at present have such facilities. The ILI method also has the benefit of detecting other defects such as dents, gouges, cracks and pipe wall faults that cannot be identified by any other means.

1 INTRODUCTION

APA Group (APA) have requested Bruce Ackland and Associates Pty Ltd (BAA) to provide an opinion regarding:

1. Accepted good industry practice in relation to modification of pipelines that are not able to be in line inspected (ILI) to permit ILI and;
2. The adequacy of other methods of detecting metal loss due to corrosion.

A brief description has been provided of the corrosion process that leads to metal loss and the normal methods of corrosion protection. A description then follows of the importance of ILI in providing the only unambiguous method of detecting metal loss at specific locations other than to excavate and visually inspect the pipe surface in an exploratory manner.

2 CORROSION, COATINGS AND CATHODIC PROTECTION

2.1 Corrosion Processes

Corrosion of buried steel pipelines normally occurs when the steel pipe wall is exposed to a corrosive environment such as soil or ground water. Corrosion can range from being general in type whereby moderate rates of metal loss might be in the order of a few tenths of mm per year or less, to much higher rates of corrosion in the presence of severely corrosive soils and especially in the presence of microbiological influences such as sulphate reducing bacteria (a relatively common form of bacteria in soils) or stray traction currents from electrified train and tram activity. Corrosion rates of several mm per year or more can be experienced under these latter circumstances and full wall penetration can occur in months or less under the more extreme cases.

2.2 Coatings and Cathodic Protection

Corrosion protection for buried steel pipelines is normally achieved by attempting to isolate the pipe from the soil by the application of coatings and with the addition of cathodic protection (CP) to protect any bare metal exposed at the inevitable areas of coating damage and deterioration. CP for steel pipelines is comprehensively covered by the Australian Standard AS2832.1 “Cathodic protection of metals, Part 1: Pipes and cables” and by Victorian state legislation such as the Electrical Safety Act 1998 (Part 9 – Cathodic Protection and Mitigation of Stray Current Corrosion) and the Electrical Safety (Stray Current Corrosion) Regulations 2009.

The application of combined CP and high quality coatings is standard practice worldwide for metallic hydrocarbon pipelines. CP is applied by either attaching galvanic anodes to the pipe (e.g. typically magnesium or zinc alloys in soils and most waters and aluminium and zinc alloys in seawater) or by applying current to the pipe using buried or submerged anodes and a DC power supply (called impressed current CP or ICCP).

2.3 Shielding

Although CP can protect bare steel exposed directly to the soil at coating defects or at areas of coating damage, it cannot penetrate far beneath disbonded coatings (coatings detached from the pipeline which allows water to reach beneath the coating), nor can the CP current reach other shielded locations such as within a protective steel casing that is short circuited to the pipeline or under high resistance material such as rocks, plastic sleeves, rubbish or insulating casings.

The CP current is limited or excluded at these shielded locations due to the high electrical resistance to current flow presented by the limited electrolytic geometry within crevices, air gaps that isolate corroding zones and very high resistance of insulating materials.

3 DETECTING AREAS AT RISK OF CORROSION

The so-called direct assessment (DA) method is the process of detecting and identifying the most opportune locations for excavation and physical examination of the pipe wall.

The most common methods of detecting locations where corrosion might be occurring is to assess a combination of survey results including, but not limited to:

- Direct Current Voltage Gradient (DCVG) surveys which detect areas of coating faults, particularly coating holidays where the pipe metal is directly exposed to the soil or water;
- Detailed CP surveys at dedicated test points which determine areas where the CP might not be adequate;
- Close Interval Potential Surveys (CIPS) which involve potential measurements above the pipeline route at close spacings of about 1m which identify more accurately those locations lacking in adequate CP and especially when correlated with coating defects detected during DCVG surveys;
- Areas of substantial stray traction current activity, especially areas displaying predominantly adverse interference effects and;
- Examination of historical records of high risk corrosion zones or leak history.

None of these methods will determine whether corrosion activity is actually occurring, but they will indicate where the normal criteria for cathodic protection are not being met. They will not indicate whether there has been any metal loss.

It is important to understand that these tests cannot be used to identify the risk of corrosion in any shielded areas such as under disbonded coatings or where pipelines are contained within casings. These shielded areas will usually go undetected except when there is an exploratory excavation at accessible locations deemed to be at high risk. Other pipeline areas where these methods cannot be used include beneath busy roadways or river crossings where access to the area to be inspected is severely restricted, prohibited or impossible.

These DA methods are essential in identifying areas where the CP may not be effective and where excavations are needed to repair coating damage, however such excavations are exploratory in nature when attempting to identify metal loss from corrosion.

A major dilemma arises when multiple coating defects are identified during a DCVG survey. It is not uncommon for an older pipeline to display numerous coating defect anomalies. In some cases there may be tens of defects per kilometre. Each one of these locations has the potential to contain disbonded coating around the coating defect and although the CP or CIPS survey might indicate the metal that is directly exposed to the soil is protected, it cannot identify whether there is corrosion occurring beneath the disbonded coating.

Attempts are then usually made to determine which are the largest defects in an effort to repair them as the highest priority. The Australian Standard AS 4827 “Coating defect surveys for buried pipelines, Part 1: Direct current voltage gradient (DCVG)” is clear in stating the method is used to determine the location of coating defects and further states the correlation between the test results and defect size depends on a number of limiting factors. There is often little or no correlation between test results and defect size (except when all environmental and electrochemical factors are identical at every defect, which is rarely the case). If an unambiguous assessment of the presence of metal loss due to corrosion were needed then every one of the coating defects would need to be excavated and repaired.

4 IN LINE INSPECTION AND THE DETECTION OF METAL LOSS

In Line Inspection (ILI) involves inserting a device, normally referred to as an intelligent pig, into the pipeline. The ILI device may carry equipment capable of conducting tests such as magnetic flux leakage and ultrasonic thickness measurements to identify loss in wall thickness due to any reason including corrosion, as well as other test equipment such as acoustic emission for crack detection (e.g. stress corrosion cracks), calipers and precise positioning equipment. The ILI device moves along the direction of product flow in live pipelines at controllable speeds and its location is accurately tracked. Tests are then conducted continuously along the accessible length of the pipeline. These tests can identify the exact location within the pipeline, position around the pipe circumference and extent of flaws including loss of wall thickness due to corrosion, cracks, dents, gouges, deformation, misalignment at joints and any other defects that alter the normal dimensions of the pipe wall. The results of the ILI are a list of anomalies and their precise location and dimensions. These anomalies can then be assessed for their severity and prioritised for repair in a timely and efficient manner.

Running an ILI tool through an area with multiple coating defects identified during the routine CP and DCVG surveys will also positively identify which of those defects, if any, are associated with metal loss. This greatly simplifies the risk assessment process and reduces the number of excavations required.

ILI therefore offers the only way to positively identify external metal loss in pipelines due to corrosion, other than to excavate and visually observe the pipe surface. Even excavation at every single location identified during CP, CIPS and DCVG surveys will not identify corrosion within casings and other locations normally inaccessible to the survey crew. It is therefore accepted that good industry practice for high pressure transmission pipelines is to use ILI to directly detect corrosion and other anomalies where possible and practical.

ILI is utilised worldwide by the pipeline industry and extensive research and development continue to be invested in making ILI more practical, cost effective and with increased accuracy.

5 CONCLUSIONS

It is considered good engineering and economic practice to install ILI facilities on pipelines which are considered important but which do not at present have such facilities. ILI is the only method capable of detecting the presence of metal loss from corrosion, other than by exploratory excavations and direct visual inspection. The ILI method also has the benefit of detecting other defects such as dents, cracks, gouges etc. that cannot be identified by any other means.

Dr Bruce Ackland
Principal Corrosion Scientist
Bruce Ackland and Associates Pty Ltd
14 August 2017

APPENDIX A

Bruce Ackland
Curriculum Vitae

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DR BRUCE G. ACKLAND B.Sc. (Hons.) Ph.D.

Member of the Australian Institute of Physics
Member of the Australasian Corrosion Association
ACA Certified Corrosion Technologist

1985-Present **BRUCE ACKLAND & ASSOCIATES PTY LTD** MELBOURNE

Principal Corrosion Consultant. Responsible for the design, investigation, administration, installation and supervision of cathodic protection and corrosion related projects.

Major projects include:

- Design, installation and supervision for major well casing and pipeline cathodic protection systems in the Cooper Basin, S.A.
- Australia's largest steel in concrete cathodic protection system for Mt Newman Mining Co.'s Ore Pier, W.A., including upgrading of the piling CP systems.
- Detailed site investigations and deep anode well installations for MLNG petrochemical plant, Sarawak, Malaysia, protecting piping, piling and foundations.
- Full design, installation and commissioning of Nabalco's Sea Water Pump Station and Mooring Dolphins reinforced concrete and piling cathodic protection systems, N.T.
- Diagnostic surveys and cathodic protection designs for reinforced concrete and immersed steel structures throughout BHP Steel, Port Kembla Steel Works and Inner Harbour.
- Extensive field surveys, cathodic protection design works, installation and commissioning across BHP Australia Coal central Queensland operations.
- Investigation and remedial works on extensive multiple pipe easements for Shell Refining Co., Malaysia, and corrosion services for Singapore based companies.
- Design, supervision and commissioning of cathodic protection systems for WMC's Olympic Dam borefield expansion facilities.
- Design, supervision and commissioning of cathodic protection systems for Victoria's State Groundwater Monitoring Network.
- Design, Superintendent and auditor for reinforced concrete cathodic protection repairs to Port of Portland shipping berths.
- Condition surveys, design, supervision and commissioning reinforced concrete and piling cathodic protection systems throughout Gladstone Port Authority's harbour facilities, including prestressed concrete and cathodic prevention systems.
- Substructure condition surveys on Vicroads coastal bridges, design certifications and monitoring of cathodic protection systems.
- Tender, design and site audits for Melbourne Water Corporation cathodic protection systems to the underside and internal surfaces of major water storage reservoirs and pipeline network.
- Marine offshore and onshore cathodic protection designs for the Gold Coast, Sydney and Adelaide desalination plants.
- Cathodic protection designs for marine facilities in United Arab Emirates, Jordan and Mauritius.
- Site investigations of AC and DC stray traction current effects on water mains in Hong Kong.
- Expert witness for Australian and Gulf of Mexico corrosion failure cases.

(Cont.)

Other cathodic protection projects have involved petrochemical plants and pipelines, well casings, internal and external storage tanks, steel mills, steel and reinforced concrete piling, shipping, offshore facilities, slurry pipelines, other miscellaneous structures and electrical hazard assessments for pipelines.

Chairman of the Australian Electrolysis Committee, Chairman of Australian Standards MT-014 and MT-014-08 committees, member of Australian Standards MT-014-03 and MT-014-06 committees, cathodic protection lecturer for the Australasian Corrosion Association, S.E. Asia training seminars and invited expert panel member for the Great Manmade River Project, Libya.

1982-1985 **DIMET CATHODIC PROTECTION AND TECHNICAL SERVICES** MELBOURNE

Corrosion Engineer. Cathodic Protection design and installation on large LPG storage vessels, Port Botany, multiple systems for alumina and coke storage tanks, wharf and loading structures. Extensive C.P. installations for oil and gas field services, petrochemical plants and buried cooling water mill pipelines. Soil resistivity and anode groundbed location works. Potential surveys, Pearson surveys, interference and stray current analysis.

Initiated and extended research into improved aluminium anode alloys and anode production. Constructed computer programs for both field and office analysis of corrosion related data.

Numerous miscellaneous cathodic protection projects involving buried vessels, pipelines, wharves, tanks and shipping.

1979-1982 **MONASH UNIVERSITY** MELBOURNE
DEPARTMENT OF MATERIALS ENGINEERING
PhD thesis "Stress Corrosion Cracking in Welded Linepipe Steel"

PUBLICATIONS

1. Berry K.J., Murray K.S., Newman P.J., Ackland B.G. and Clark P.E. “Magnetic and Mössbauer Studies on Trigonal Iron (III) Thiohydroxamate Chelates”, Conference on Co-ordination Metal Compounds, Perth (1978).

2. Ackland B.G. and Cherry B.W., “Stress Corrosion Cracking of Welded Linepipe Steel”, Proceedings of the Australasian Corrosion Association Conference 20, pp J-1-1 to J-1-8, Adelaide, 17-21 November (1980).

3. Ackland B.G., “The Stress Corrosion Cracking of Welded Line Pipe Steel”, Australian Welding Research Journal 9, pp 31-37 (1980).

4. Ackland B.G. and Cherry B.W., ”Stress Corrosion Cracking in Welded Line Pipe Steel”, Corrosion Australasian Journal 6, no.5, pp 8-11 (1981).

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Dr Bruce Ackland – Publications (cont.)

5. Ackland B.G., "Stress Corrosion Cracking in Welded Pipelines – Effect of Coatings", Joint Symposium on the Minimisation of Corrosion in Welded Structures, Australasian Corrosion Association and Australian Welding Research Association, Melbourne, 22 Oct. (1981).

6. Ackland B.G. and Cherry B.W., "Stress Corrosion Cracking in the Weld, Heat Affected Zone and Base Metal of a Line Pipe Weld", Proceedings of the Australasian Corrosion Association Conference 21, pp1-14, Brisbane, 16-20 November (1981).
Awarded the Association's Best Paper Award.

7. Ackland B.G. and Cherry B.W., "Cathodic Disbonding of Pipeline Coatings – The Effect on Stress Corrosion Cracking", Proceedings of the Australasian Corrosion Association Conference 22, pp1-8, Hobart, 8-12 November (1982).

8. Ackland B.G. "Stress Corrosion Cracking in the Weld, Heat Affected Zone and Base Metal of a Line Pipe Weld", Australian Welding Research Journal 11, pp 48-54, (1982).

9. Ackland B.G. and Cherry B.W., "Fracture Propagation in Gas Pipelines Containing Stress Corrosion Cracks", Proceedings of the Australasian Corrosion Association Conference 23, paper 11, Sydney, 14-18 November (1983).

10. Ackland B.G. and Franklin R.K., "Cathodic Protection of a Major Reinforced Concrete Ore Pier", Proceedings of the First Structural Engineering Conference, Institution of Engineers Australia, Melbourne, 26-28 August (1987).

11. Ackland B.G., "A Description of the Corrosion and Cathodic Protection of Steel in Concrete", Proceedings of the Australasian Corrosion Association Conference 33, paper 47, Newcastle, 21-25 November (1993).

12. Ackland B.G., "Comparisons of Some Common Cathodic Protection Formulae for Non-Uniform Conditions", Proceedings of the Australasian Corrosion Association Conference, CAP97, paper 40, Brisbane, 9-12 November (1997). Awarded the Association's Best Review Paper Award.

13. Ackland B.G. "Making Sense of Half Cell Potential Measurements of Reinforcing Steel in Concrete", Proceedings of the Australasian Corrosion Association Conference, CAP98, paper 30, Hobart, 23-25 November (1998).

14. Ackland B.G. "Reference Electrodes and Cathodic Protection", Proceedings of the Australasian Corrosion Association Conference, CAP99, paper 19, Sydney, 21-24 November (1999).

15. Ackland B.G. "Cathodic Protection of Well Casings", Proceedings of the Australasian Corrosion Association Conference, CAP2000, paper 30, Auckland, 19-22 November (2000).

16. Ackland B.G. "Reference Electrodes and Cathodic Protection", Corrosion and Materials 26, no.4, pp S6-S8 (2001).

Dr Bruce Ackland – Publications (cont.)

17. Ackland B.G. "Cathodic Protection of the Human Genome", Proceedings of the Australasian Corrosion Association Conference, CAP-02, paper 62, Adelaide, 10-13 November (2002).

18. Ackland B.G. "Cathodic Protection of the Human Genome", Corrosion and Materials 28, no.4, pp S1-S4 (2003).

19. Ackland B.G., Franklin, R.K. and Micalizzi, A. "Case Study – Cathodic Protection and Cathodic Prevention of a Reinforced Concrete Wharf", Proceedings of the Australasian Corrosion Association and Australian Institute of Non-Destructive Testing Conference, AINDT & CAP-03, paper 116, Melbourne, 23-26 November (2003).

20. Ackland B.G. "Attenuation of Current Along Cathodic Protection Anodes", Proceedings of the Australasian Corrosion Association and Australian Institute of Non-Destructive Testing Conference, AINDT & CAP-03, paper 87, Melbourne, 23-26 November (2003).

21. Ackland B.G., P.F. Thompson Memorial Lecture "Cathodic Protection – Black Box Technology?", Proceedings of the Australasian Corrosion Association Conference, CAP-05, paper 4, Gold Coast, 20-23 November (2005).

22. Ackland B.G., "Cathodic Protection – Black Box Technology?" Corrosion and Materials 31, no.3, pp 20-25 (2006).

23. Ackland B.G., "Cathodic Prevention", Proceedings of the Australasian Corrosion Association Conference, CAP-06, paper 64, Hobart, 19-22 November (2006).

24. Ackland B.G., "Cathodic Prevention", Corrosion and Materials 32, no.4, pp 10-14 (2007).

25. Edmond L., Cope G., Bryson A., Ackland B. and Forsyth M., "An Evaluation of Holiday Detection Voltages for FBE Coated Pipe", Proceedings of the Australasian Corrosion Association Conference, CAP-09, paper 24, Coffs Harbour, 15-18 November (2009).

26. Ackland B. G., "Limitations of the Stray Current Interference Criteria", Proceedings of the Australasian Corrosion Association Conference and International Corrosion Congress, CAP-11, Paper 202, Perth, 20-24 November (2011).

27. Ackland B. G., Plenary Lecture, "Cathodic Protection – It Never Sleeps", Proceedings of the Australasian Corrosion Association Conference, CAP-12, Melbourne, 11-14 November (2012).

28. Ackland B. G., "Cathodic Protection – It Never Sleeps", Corrosion and Materials 37, no.6, pp 50-57 (2012).

29. M. Büchler, B. Ackland, U. Angst, "The historic evolution of cathodic protection criteria", in CEOCOR international Congress 2016 Ljubljana, CEOCOR, c/o SYNERGRID, Brussels, Belgium, (2016).