ACOUSTIC EMISSION MONITORING AS A TOOL IN RISK BASED ASSESSMENTS

By Dr Gary Martin and John Dimopoulos

ATTAR - Advanced Technology Testing and Research
A division of Engineering Materials Evaluation Pty Ltd ABN 14 006 554 785
Unit 27, 134 Springvale Road, PO Box 286, Springvale Victoria 3171
T (03) 9574 6144 **F** (03) 9574 6133 **E** admin@attar.com.au www.attar.com.au

In recent years the use of risk based assessments has significantly increased and more operators are interested in prioritising plant inspection in terms of their structural integrity, rather than relying on a traditional time based inspection interval. Acoustic Emission is another tool that can be used to determine the condition of a piece of plant with very minimal interruption in plant processes and significantly reduced costs compared to the alternative NDT inspections methods which require internal inspections.

This paper covers the basics of acoustic emission and its application in testing of above ground storage tanks, pressure vessels and elevating work platforms. This includes test set up, test procedures and data analysis. It shows how Acoustic Emission may be implemented in risk based assessment.

1. INTRODUCTION

Acoustic Emission (AE) has been used for some time now in various industrial applications [1] as an NDT tool, these include monitoring fiberglass structures such booms in elevating work platforms (EWP's), tanks and pipes, above ground storage tanks (AST's) and pressure vessels. Its has long been used to screen fiberglass booms in the United States, New Zealand and Australia because it is the only technique that can efficiently detect internal discontinuities and indicate structural integrity at the same time. Its application to determining the condition of above ground storage tanks has been used throughout the United States and Europe since the late 1980's. By listening to the tank floor for corrosion and leaks using AE, it has been possible to classify the tank condition in order to prioritise its maintenance. AE monitoring of pressure vessels has been recognised as a form of testing of pressure vessels in ASME Boiler and Pressure Vessel Code Article 12 [2] and Australian Standard AS 4037 Pressure Equipment – Examination and Testing, Section 23. [3]. It can also be applied to piping for leak, corrosion and crack detection,

An AE inspection is usually carried out during a controlled loading or pressurisation of the structure. With EWP's this takes the form of a proof load sequence, with new pressure vessels it is a proof load before service, a controlled variation of load while the structure is in service or a static head greater than 70% in an AST. AE monitoring is used for reasons of economy or safety, and a special loading procedure is arranged to meet the needs of the AE test. It also gives valuable additional information about the performance of the structure under load.

AE differs from most other non-destructive testing (NDT) methods in two key respects. First, the signal has its origin in the material itself and is not injected into the object from an external source. Second, acoustic emission detects movement, while most other methods detect existing geometric discontinuities or breaks in the normal metallic atomic structure.

A major benefit of AE inspection is that it allows the whole volume of the structure to be inspected non-intrusively in a single loading or pressurization operation. Typically, the global AE inspection is used to identify areas with structural problems, and other NDT methods are then used to identify more precisely the nature of the AE source. Depending on the case, acceptance or rejection can be based on AE inspection alone, other methods alone, or both together.

As indicated structures are usually stressed, while being monitored, to stimulate growth of discontinuities which emit acoustic emission from sources such as resin deformation, delamination and fibre breakage in fibre composites and crack propagation, elastic and plastic deformation of the structure in pressure vessels and leaks and corrosion in AST's.

The relatively high cost of equipment and specialised training required to operate and analyse the data obtained from each type of test may have limited its use in the past, but in more recent times, it appears that more people are prepared to use this technology as part of their risk based assessment programs to reduce their operating costs, by eliminating unnecessary and sometimes intrusive inspections.

Risk based inspection is a method using risk as a basis for prioritising and managing the efforts of an inspection program. It is based upon the identification of expected degradation mechanisms and a quantitative/qualitative analysis of the probability of failure, consequences and likehood of detection. AE is a cost effective way for identifying failure mechabnisms in a wide variety of materials and application. This paper covers three of the more common applications.

2. ACOUSTIC EMISSION

AE can be described as an elastic wave, that arises as a result of a sudden release of energy within a material. The energy released is characteristic of the source mechanism but is affected by the material through which it travels. Sensors mounted on the surface detect this pulse of energy. These sensors, which are typically a resonant frequency may be in the range of 20 – 500kHz. On fibre composite materials 60kHz transducers are commonly used on pressure vessels 150kHz are commonly used and on AST's 30Khz resonant frequency transducers are commonly used. These are acoustically coupled to the surface, using a couplant material, to improve transmission of AE to the sensor.

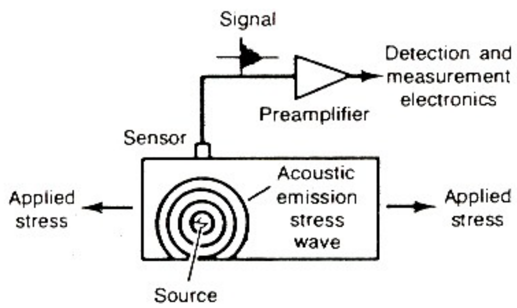

Figure 1 Generation and detection of AE from an active source under stress[4].

The signal generated by a sensor typically looks like that shown in Figure 2 . The signal has many features, commonly used to characterise it. These are amplitude, duration, rise time, decay time, AE counts and energy (MARSE). MARSE is the measured area under the rectified signal envelope. As a measure of the AE signal magnitude is preferred because it is sensitive to amplitude as well as duration.

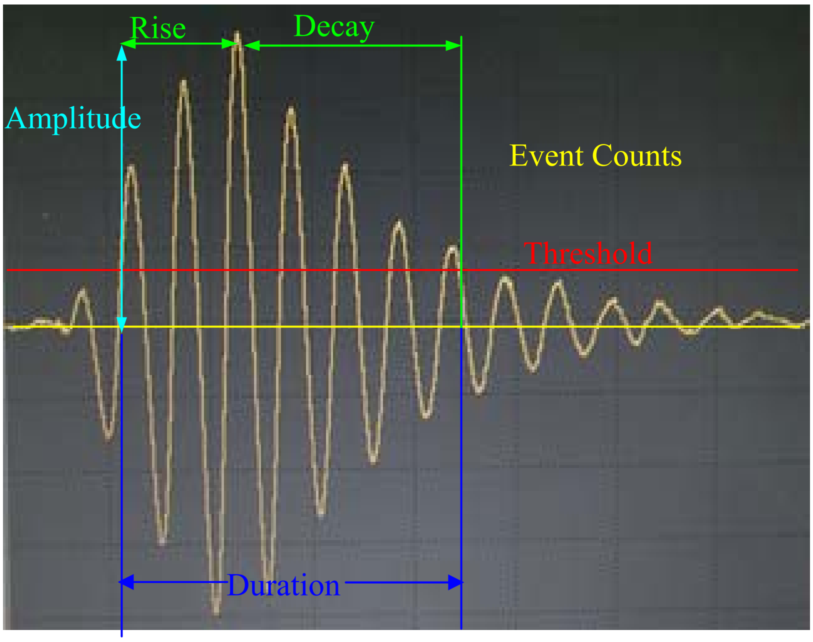

Figure 2 Characteristics of the AE pulse.

Amplitude is the highest peak voltage attained by an AE waveform. This determines the detectability of the AE event. AE amplitudes are directly related to the magnitude of the source event and they vary over an extremely wide range from microvolts to volts. The amplitudes of acoustic emissions are usually expressed on a decibel scale, in which 1 µV at the transducer is defined as 0dBae, 10 µV is 20dBae, 100 µV is 40dBae etc. Usually the amplitude of the AE signal detected is very low, thus requiring sophisticated and expensive electronics for signal detection and processing, Figure 3. . This is accomplished with a preamplifier, which is placed close to (or even inside) the sensor so as to minimise pickup of electromagnetic interference. The preamplifier has a wide dynamic range and can drive the signal over a long length of cable so that the main instrumentation can be placed hundreds of metres from the test component if necessary.

The preamplifier typically provides a gain of 100 (40 dB) or 1000 (60dB) and includes a high-pass or most commonly bandpass filter to eliminate the mechanical and acoustical background noise that prevails at low frequencies. Typical bandpass is 100 to 300 kHz, when using the 150 kHz resonant frequency sensor.

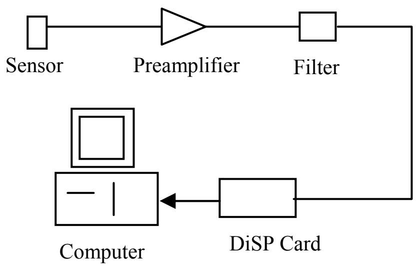

Figure 3 Typical single channel AE system

The equipment used by ATTAR for testing is Physical Acoustics Corporation (PAC) DiSP Boards, with AEWin Software, 2D location option as well as Noesis software for research and testing applications, Figure 4.

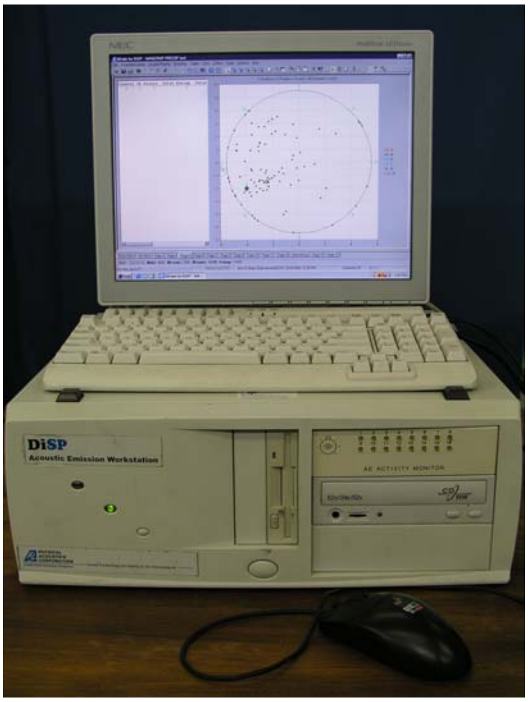

Figure 4 PAC DiSP AE monitoring system showing AST bottom location results.

Sensors are mounted according to the requirements of ASTM E 650-85 Standard Guide for Mounting Piezoelectric Acoustic Emission Sensors [5] using Vaseline or heavy duty grease as a couplant, Figure 5. All paint must be removed because it can result in between 80 to 100% received AE signal amplitude reduction depending upon whether it is well bonded through to not bonded to the substrate.

System calibration is required prior to testing to ensure all sensors are working and that the sensitivity of each channel used is similar. Calibration is commonly achieved using breaking 2H, 0.3 mm diameter lead pencil [6] as shown in Figure 5 or by electronically pulsing the system using suitable sensors, such as PAC R15I AST (Automatic Sensor Test) sensors.

Figure 5 Sensor mounted on steel vessel during calibration.

3. APPLICATIONS

3.1 Fibreglass booms on Elevating Work Platforms

Conducted in Australia since the early 1980's and more recently to AS 4748:2001 [7] this requires a load between 1.25 and 1.5 times the Safe Working Load to be applied in a two stages, Figure 6. Four sensors placed on the top and underside of the boom are used to monitor AE. Defects undetectable by conventional NDT such as those shown in Figure 7 have been found.

Figure 6 Typical set up for monitoring EWP boom

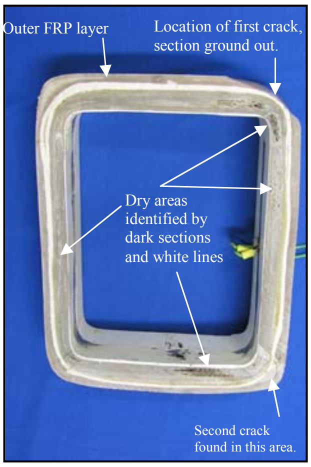

Figure 7 Defects undetectable via conventional NDT

The advantage of an AE test is that it detects all active defects in the fibreglass boom, as well as movement at the steel/FRP splice and assists in identifying hydraulic system leaks. It does not damage the boom, unless it is already defective. An AE test conducted by a competent operator also removes the burden of responsibility from managers untrained in the non-destructive testing of FRP.

Inspection intervals should be set by the owner who should have an understanding of his local work conditions and equipment use. These should be based on the requirements of the Standard [7] which are:

Booms involved in an accident shall be retested immediately after the accident to determine the feasibility of repairs. or guidance, the following intervals before retesting are recommended:
(a) Booms giving less than a total of 10 acoustic emission events 12 months.
(b) Booms with high damage potential, e.g. booms used for tree lopping, replacement of poles, transformers, cross arms or conductors, and demonstration of abseiling techniques .... 12 to 24 months.
(c) Booms with lower damage potential, e.g. booms used for light globe replacement, painting and cleaning .... 4 to 5 years.

3.2 Pressure Vessels

One major application of AE has been to determine the structural integrity of pressure equipment. This is usually done to ASME [2] or ASTM [8] Standards. Vessels to be tested require very little preparation and are usually only required to be unpressurised or run at a lower than normal operating pressure for 12 hours before testing. During testing, all possible sources of extraneous acoustic noise such as vibration, friction or fluid flow must be eliminated.

Sensors are mounted on the vessel, paint being removed only from the area where the sensor is mounted. On insulated vessels, only small sections of insulation needs to be removed from an area approximatly 20 x 20 cm, where the sensors are to be mounted.

The number of sensors used depends upon the size of the vessel to be tested and is determined from the attenuation of simulated AE signal, Figure 8. Attenuation is determined by breaking the pencil lead and recording the amplitude of received signals at different distances.

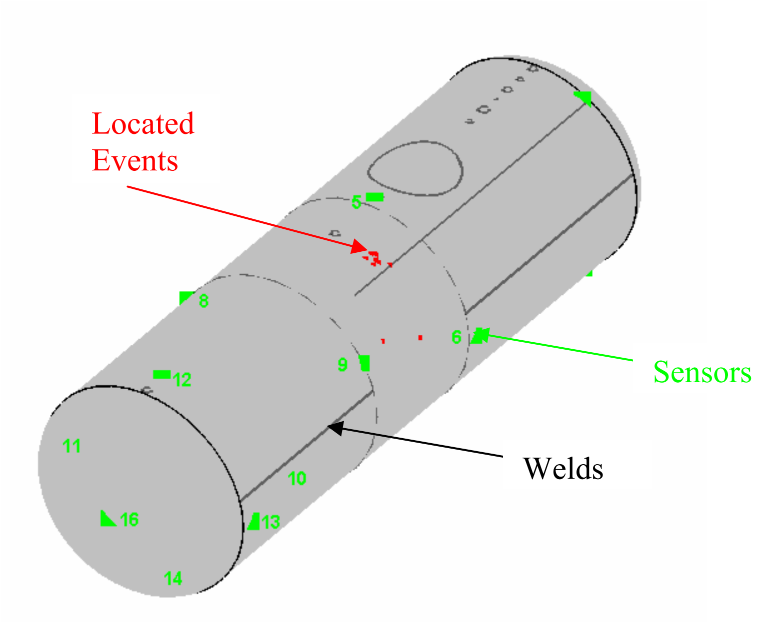

Figure 8 Drawing of vessel to be tested, green squares indicate sensors position, weld seams and pipe fittings are also drawn. Red dots are simulated events located on surface.

The vessel is then pressurised to 10% above its maximum operating pressure in the last 6 months of operation. The pressurisation sequence used is shown in Figure 9.

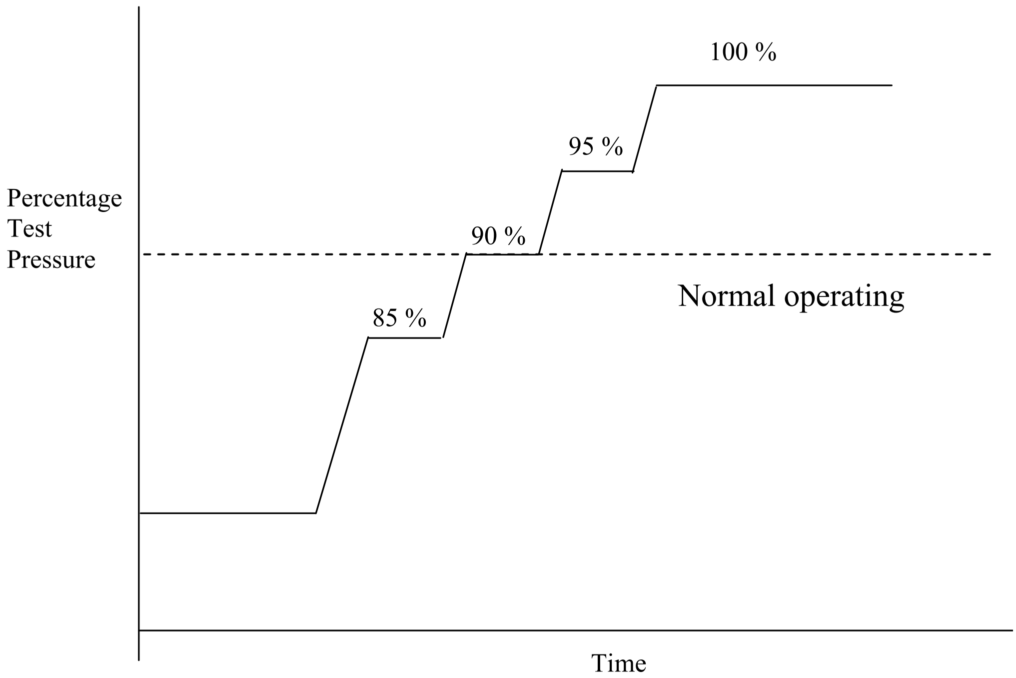

Figure 9 Pressurisation program, all hold periods are 10 minutes except for last which is 30 minutes.

Any defects, stimulated by the pressure applied, generate AE that may be detected by the sensors. Non-active discontinuities, not stimulated by the pressure, do not generate AE as they are passive and will not propagate in service.

The data recorded is then analysed to determine it meets certain criteria with respect to the number of events recorded during the loading and hold period, total number of counts, amplitude of events and also the intensity or severity of the AE increase during the loading sequence. Any channels or clusters of events, located on the vessel and not meeting the criteria, such as those shown in Figure 5, are further analysed using an energy intensity analysis to determine the severity of the anomalies which are then rated on a scale from 0 to 5. Table 1 lists a description of the six (6) different anomalies.

Level	Anomaly Description	Action
0	Insignificant	No follow-up required
1	Minor Anomaly	Note for future reference
2	Minor Anomaly	Note for future reference and check for surface defects such as rust, pitting or gouges
3	Anomaly	Requires follow-up, using either further data analysis, retest or appropriate NDT method.
4	Significant Anomaly	Immediate follow-up inspection required using appropriate NDT method.
5	Major Anomaly	Plant shut down immediately, with follow-up inspection required using appropriate NDT method

Table 1 Summary of anomaly indication and action

To date we have tested many different types of vessels from spheres to vertical and horizontal vessels. In the example shown in Figure 8, a 2.4 m diameter 7.15 m long vessel was tested using a total of 16 sensors to cover the entire vessel.

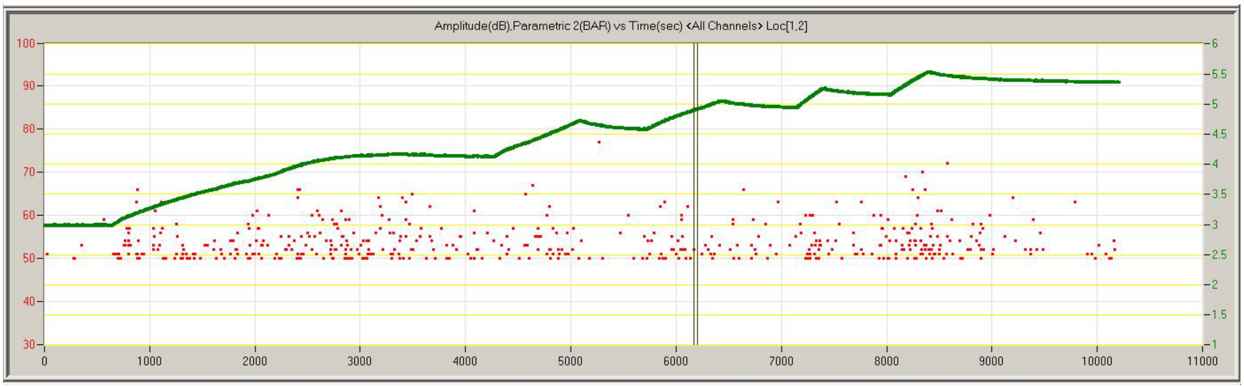

Figure 10 Test results for vessel, green line is pressure in vessel while red dots indicated AE activity versus time.

Analysis of data showed that although a number of events were recorded only one significant cluster of events was located on the vessel and is labelled as cluster Z, Figure 11.

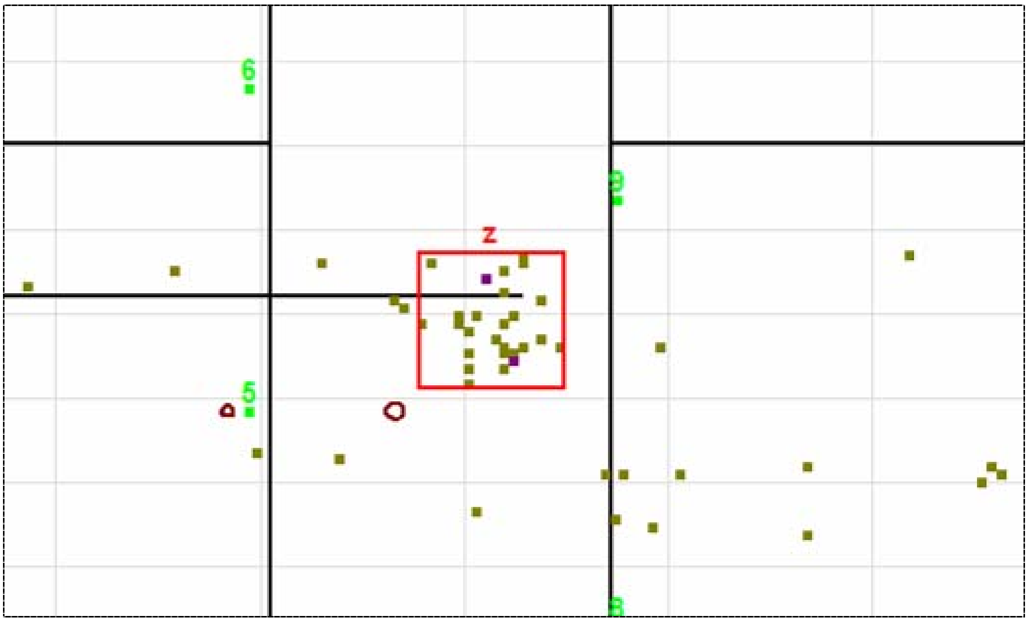

Figure 11 Closer view of cluster Z of events located at walkway weld.

This area coincided with a walkway and analysis of the events in cluster Z, Figure 11, indicated the number of events increased with respect to the load and displayed a slight increase in their amplitude. The energy levels of the events classified it as a level 2 anomaly which required no further follow-up, however, as the area was readily accessible, it was decided to further investigate the area using an angle beam ultrasonic inspection which did not reveal any anomalies in this area. Visual inspection of the area, however, did reveal the presence of corrosion on the surface, which may have explained the cluster of AE events located.

3.3 Monitoring above ground storage tanks.

Another major application of AE has been the testing of above ground storage tanks to determine the condition of the floor plate, which cannot normally be examined without emptying and entering the tank to conduct either ultrasonic B-scan or magnetic flux leakage tests.

Tanks to be tested are first taken off line for a period of 6 to 12 hours prior to testing and all agitators, heaters and pumps are turned off. Six to twelve sensors are then mounted around the circumference of the tank approximately 0.5 to 2 metres from the knuckle as shown in Figure 12, depending on the size of the tank. Guard sensors can also be employed in order to filter background noise being generated in the upper section of the tank.

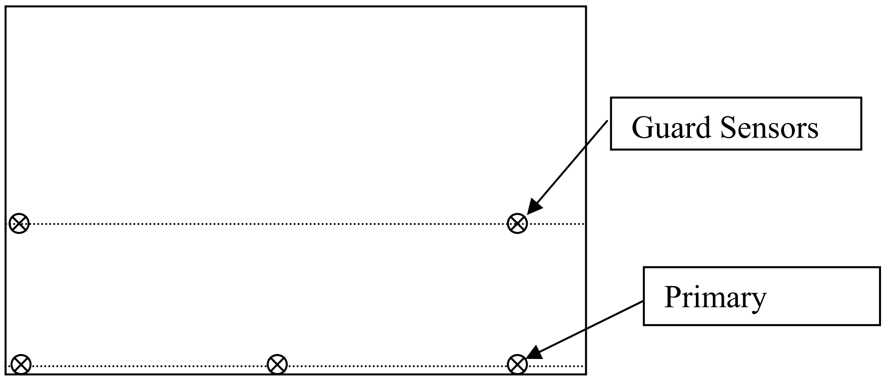

Figure 12 Sensor layout on above ground storage tank. (Side elevation)

The sensors are then connected to the acoustic emission computer and calibrated using the standard lead pencil. With all agitators, pumps turned off and no fluid movement into or out of the tank, data is recorded for a minimum of 1 hour. The data is then analysed and plotted using a two dimensional tank bottom location package from PAC, Figure 13.

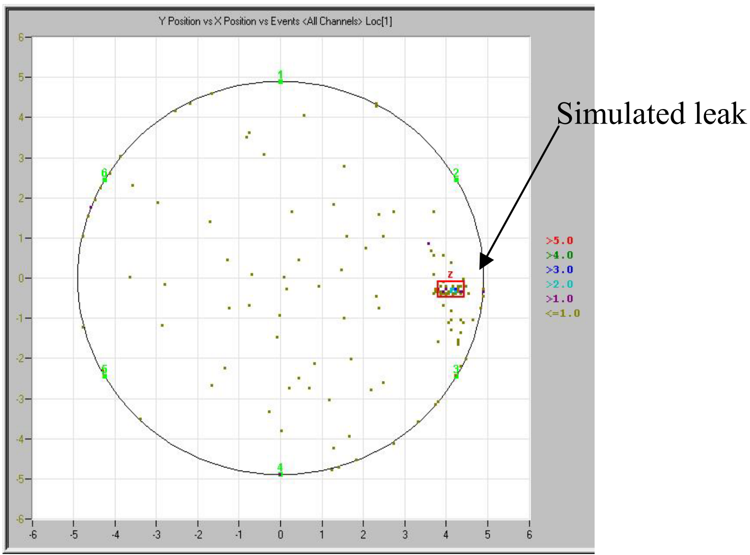

Figure 13 Location of a simulated leak in a storage tank.

The data is also filtered to eliminate as much background noise as possible and its characteristics analysed to identify any leaks in the tank.

The analysis is also used to grade the tank into one of six classifications as detailed in Table 1 below.

Classification	Activity	Action	Time Frame	Work required
A	Very Low	Retest	5 years	
B	Low	Retest	3 years	
C	Medium	Retest	1 year	
D	High	Open	Within 1 year	Inspect internally
E	Very High	Open	Immediately	Inspect internally

Table 2 Tank grading based on AE test results.

From this classification, maintenance can then be scheduled on a needs basis. Tanks that produce low activity do not have to be inspected, thus saving many dollars in unnecessary inspections. The benefits are not only economical, but also environmental, as cleaning tanks with hazardous or poisonous goods poses problems with waste disposal.

Correlation of acoustic emission test results, conducted by an independent user group [9], was carried out where results from acoustic emission tests were compared to subsequent internal inspections. The authors found that 100% of "A" grade tanks had no damage and did not require repair and that 60% of "E" grade tanks had major damage requiring repairs or floor replacement.

The analysis indicates a high degree of confidence with the results from a tank producing very little AE and that it is only when there is a significant amount of AE detected that difficulties arise in identifying and classifying defects in a tank. This is due to difficulties encountered in identifying and eliminating noise in a relatively noisy environment.

4. CONCLUSION:

AE testing is also a valuable tool for evaluating the condition of a range of materials and structures including fibreglass booms, pressure vessels and above ground storage tanks. By determining their condition the structures that require urgent attention can be identified and scheduled for maintenance, while a good structure can be left in service and if maintenance carried out when required rather than at fixed time intervals.

The cost of an AE inspection on pressure vessels and tanks is only a fraction of the price of an internal inspection, so that an AE inspection allows money, time and resources to be saved. There are even environmental benefits by not emptying and cleaning tanks that do not require inspection or work to be carried out on them. There is also very little disruption to plant operation, as structures only have to be taken out of service for a short period of time.

AE should be used as the basis of any risk based assessment of in-service structure because it is a cost efficient way of assessing structural fitness for purpose.

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