

I. COMPARISON OF CORROSION MONITORING SYSTEMS IN THE OIL AND GAS INDUSTRY



The oil and gas industry sector has implemented various choices and strategies for corrosion detection and monitoring in the past 50 years. Some of these approaches are very well consolidated, some others are emerging.

This white paper aims to clarify the pros and cons of different approaches for corrosion monitoring in terms of detection, implementation within integrity strategy and costs.

a. ER Probes

ER probes are applied in the oil and gas industry since several decades and are therefore a well-established approach for corrosion monitoring. ER probes are intrusive probes capable of measuring corrosion rates as an increase in electrical resistance over time. A metal tip element is introduced into the process fluid and it's electrical either via a data logger or wirelessly. The corrosion of the metal tip is used to infer the corrosion speed experienced by the metal structure.

This corrosion monitoring approach is simple to use, does not require highly trained personnel and is well regulated.

However, ER probes are affected by a number of shortcomings listed below:

- ER probes are intrusive, therefore increasing the risk of failure while mounting and during standard operation. As the tip needs replacement at least every 3 years the retrieval and replacement is critical and several safety incidents during such operations have been recorded such operations have been recorded in the oil and gas industry;
- ER probes installation cannot be carried out during normal operations;
- The position at which the corrosion is measured on the probe face in most cases does not experience the same level of corrosion as the pipe wall;
- Affects the internal flow as the ER probe introduced within the fluid deviates the flow and could induce corrosion downstream;
- Is affected by the fluid as some viscous deposit that would tend to cover the tip may hide the real corrosion rate of the pipe wall;
- Does not work well with localized corrosion;
- On buried locations needs excavation before retrieval. This hugely increases the maintenance costs;
- It applies only to internal corrosion.

b. Corrosion Coupons

Corrosion coupons have been used since 50 years ago in the oil and gas industry and are therefore well-known tools for corrosion monitoring. The coupons are made of a weighed metal alloy introduced into the process fluid. As the metal coupon corrodes it loses weight. The coupon is later retrieved and substituted with a new one within a reasonable time (linked to the expected corrosion rate). The coupon is then sent to a lab that measures its weight and works out the metal loss.

Corrosion coupons are a simple way to obtain corrosion rate. However, they do carry all the disadvantages already mentioned for the ER probes and some additional ones listed below:

- Very high maintenance costs as the coupon should be retrieved frequently (for example on a monthly basis);
- Higher risks due to frequent intrusive access;
- Measurement is only an average within the period used so maybe meaningless if the corrosion rate is likely to change more rapidly than the retrieving interval;
- The surface of the metal coupon is well polished and maybe affected by corrosion in a completely different way compared to the structure under examination;
- Companies tend to place these coupons at locations where they are easy to install because of the frequent retrieval rather than in the most meaningful location. For example on above ground length of pipe rather than on the buried part or at the 12 o'clock rather than the 6 o'clock. These bad practices are very common and greatly diminish the effectiveness of a corrosion monitoring campaign based on corrosion coupons.

c. Manual UT readings

Manual ultrasonics is probably the most utilized approach for 'monitoring' corrosion of oil and gas assets. The technique requires an ultrasonic transducer to be close or in contact with the metal structure to be checked. The thickness is measured locally based on the time taken by the ultrasound wave to go through the thickness of the metal and be reflected by the opposite surface of the metal.

The technique is very well known and widely applied. As it requires direct access to the structure under examination and the measurement is limited to the point being measured, access should be granted on almost the entirety of the assets to be able to carry out such measurements. Therefore this approach is not suitable for buried pipelines where more complex tools such as PIG and ILI are used.

Large refineries or plants may require inspection of more than 200.000 inspection points. This is an immense task especially considering the issue of access (scaffolding, insulation removal, and reinstatement). Therefore it is generally accepted that most points are measured only every 5 years. This may not be sufficient to assure the safe operation of the plant even in the fortunate case that the points chosen are actually representative of the overall corrosion.

Manual UT readings address only some of the potential corrosion issues in refineries and plants and have several disadvantages:

- External corrosion such as Corrosion under insulation or corrosion under support are not identifiable using standard UT tools;
- Repeatability of data is very limited. So for example ASM International book on 'Corrosion in the petrochemical industry' correctly reports that "uncertainty in the readings is approximately 0.5mm (0.02in), but this can be greater if the condition of access and surface preparation are less than optimal". Due to the fact that the point tested may not be exactly the same (even a few miles difference can cause different readings), different procedures are used, different equipment is used, different operators are carrying out the inspection the results have very large scatter and in some cases are totally inconclusive as these show for example thickness increase. While plant operators would be delighted to see the thickness of their assets growing, this is, unfortunately, impossible...
- Access to the target measurement location may be expensive due to scaffolding and insulation. For example, it is well known that the cost of access is in excess of 90% of the total cost of inspection when considering insulated pipes at elevated locations.

d. Long Range UT

Long Range (LR) UT or LR Guided Waves is an emerging technique that enables to screen for external and internal corrosion from a remote location. Low-frequency mechanical waves are excited onto the structure and echoes from changes in the cross section of the metal cause echoes. These echoes are recorded and linked with the geometric features on the pipe under examination therefore enabling to detect corrosion. The technique is applied mainly on pipes. The advantages of this approach are that it does not need direct access to the structure under examination, the area inspected is very large compared for example with UT approach and it can detect both external and internal corrosion. However there are several disadvantages:

- The range is affected by the geometry of the pipe, the fluid inside the pipe (including deposits), the embedding material (e.g. soil) and the coating.;
- It can detect only large corrosion patches. Not useful for localized pitting;
- Does not give direct measurement of metal thickness loss, only an indication of presence of an anomaly;
- It cannot be used to reliably detect corrosion in the immediate proximity of other pipe features (such as welds, pipe supports, branches, flanges and similar);
- It is strongly dependent on operator skills.

e. PIG and ILI

PIG and ILI are tools that enable to inspect pipelines from the inside. These tools are equipped with several types of detection and measurement technologies (such as for example UT and MFL) which provide thickness values at several locations around the circumference and along the length of the pipe. The advantage of using such tools is the large portion of pipe inspected compared to any other technique. However there are several shortcomings:

- Most assets within refineries and plants are not suitable to be inspected using PIG or ILI;
- A large percentage of transmission pipelines are not piggable;
- Inspection can only be periodic as there are large costs involved, normally only every 5 years. This affects the capability to detect corrosion issues due to changes in fluid or external condition.

II. OVERVIEW OF A3 MONITORING SPOTON TECHNOLOGY FOR CORROSION MONITORING

A3 Monitoring designs and manufactures a range of sensors utilized for corrosion, leak, third party damage and theft monitoring. Here we will only describe the tools used for corrosion monitoring. A3 Monitoring sensors require minimum to zero infrastructure, are very easy to apply and provide reliable, precise and frequent data. The sensor used to detect corrosion are as follows:

1. SpotOn® U - based on ultrasonic thickness monitoring technology
2. SpotOn® LR – based on Long Range ultrasonic monitoring technology
3. SpotOn® AE – based on Acoustic Emission Monitoring technology

The above-mentioned sensors are integrated together for best performance and greatly improved detection capability. This is a totally unique feature of A3 Monitoring sensors. Where all other corrosion monitoring sensor providers would need to adapt corrosion monitoring strategies to suit their sensors capability, A3 Monitoring would choose the best combination of available solutions, therefore, generating large cost reduction as well as improved POD (Probability of Detection).

a. SpotOn® U

SpotOn® U is a real-time corrosion monitoring solution designed to provide remote and frequent thickness data to asset owners. The system is sensitive to small changes in wall thickness, withstands very harsh environmental conditions and can be applied on above ground, insulated, buried and subsea pipes.

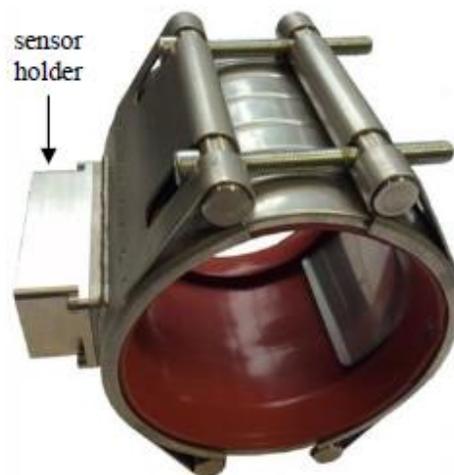


Figure 1

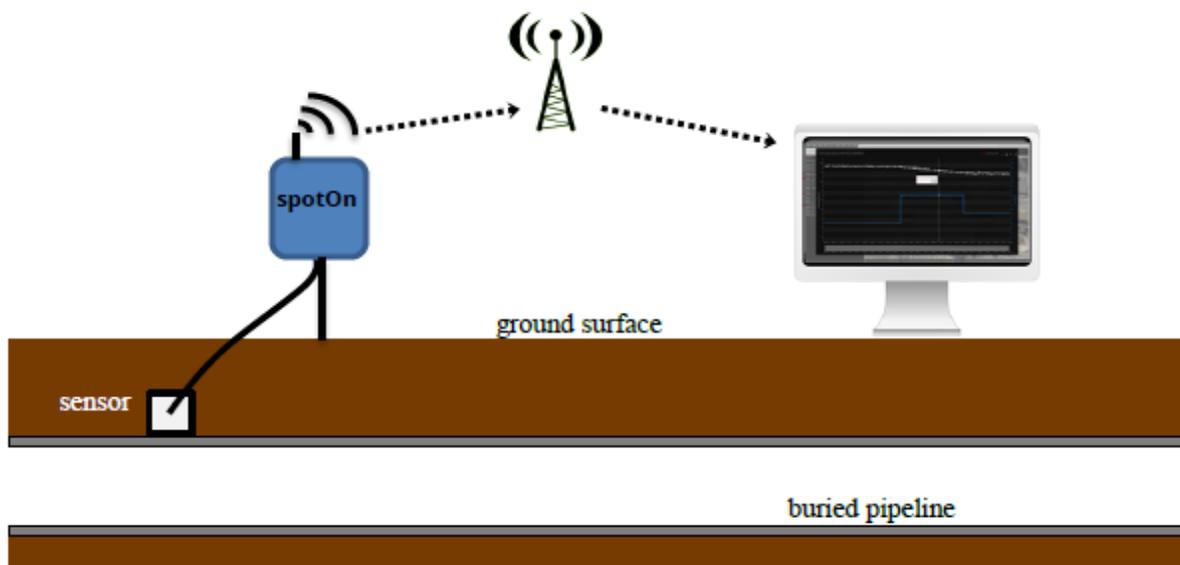


Figure 2

The spotOn® U unit is attached to the pipe using a stainless steel repair clamp with protective silicone on the inside and a sensor holder that protects the sensor and its electronics while enabling for the sensor to touch the outside of the pipe (see Figure 1). The silicone makes contact with the pipe and creates the seal between the clamp and the pipe (there is no metal-metal contact with the pipe). Up to 8 sensors can be attached to a single clamp, therefore, enabling to monitor several clock positions. A temperature sensor is installed at each UT sensor location so that precise thickness trend is achieved using temperature compensation algorithms. The system can be installed either as a permanent or a temporary installation, offering great flexibility to reposition the sensor. Figure 2 shows a typical spotOn® U setup where the UT sensor is attached to the pipe at a buried location. The UT signals are transferred to a battery powered control unit via a rugged cable and encrypted data are sent to a dedicated server via satellite, GSM or SCADA. Data logger option is also available.

Data is, therefore, de-encrypted and displayed on the shieldCube software. Using satellite link the need for client infrastructure is cut to zero. In this case, there is no need for local servers or local networks or local facilities. The system is designed to be easy to install plug-and-go solution.

The batteries last a minimum of 5 years and the unit can be upgraded with an extra battery pack to increase to 10 years their duration. The latest version of spotOn® U is also available with solar power rechargeable batteries, therefore, enabling to virtually cut to zero the need to return to the site. This is especially useful in harsh environments.

SpotOn® U enables the operators to:

- Quickly establish thickness trends in order to optimize inhibitors strategy
- Increase profitability by flowing and processing variable fluids
- Cut to zero access costs even in areas difficult to access such as buried pipes
- Have great repeatability and improved sensitivity compared to other similar corrosion monitoring tools.

Figure 3 shows some example of spotOn® U corrosion monitoring at a downstream installation. As clearly visible from this result, corrosion trend was changing very rapidly depending on the fluid flowing within the pipe being monitored. Precise and reliable daily measurements were sent to the client enabling to identify the inhibitor performance depending on the fluid and later rectify the issue of large corrosion rate by further optimizing its inhibitor injection strategy. As any other UT monitoring tool also spotOn® U has limited area coverage and focuses only on internal corrosion. Other providers of UT monitoring sensors would normally propose to increase area coverage by increasing the number of sensors.

A3 monitoring can also provide an alternative solution that is the spot On® U+ LR. Spot On® U provides precise thickness values at certain locations. SpotOn® LR provides large coverage establishing if there is corrosion at some distance from the position where the UT sensors are located. Below we provide more information on spotOn® LR deployment characteristics and expected performance.

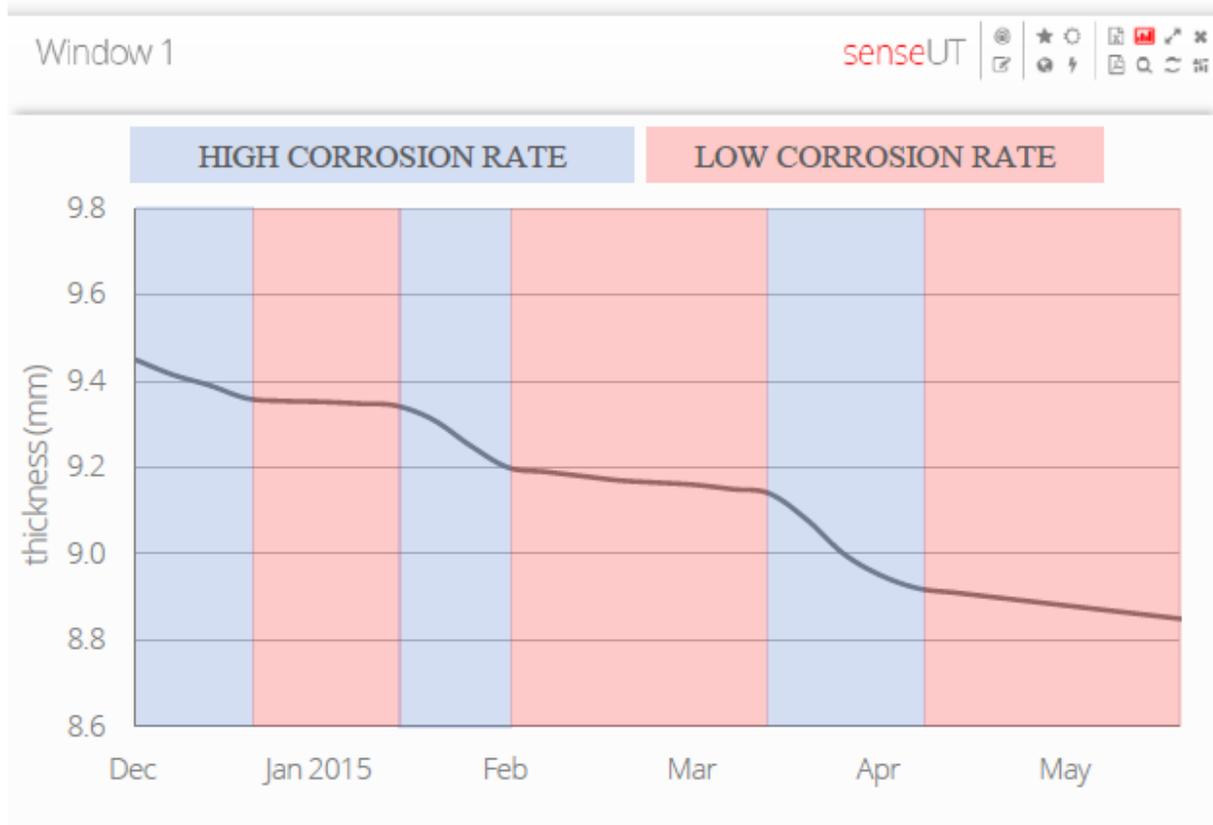


Figure 3: The chart shows typical thickness trend graph using spotOn U. Periods of high and low corrosion rate are intermitting due to changes in fluid flowing within the pipe. Based on the results above inhibitors injection was optimized in order to reduce the corrosion rate.

b. SpotOn® LR

SpotOn® LR is a corrosion monitoring solution, which leverages on an innovative patented technology to provide remote threat identification. SpotOn® LR identifies external and internal corrosion threats in pipelines which are difficult to access. The system is deployed using the same repair clamp used for spotOn® U, making the two systems fully compatible to be used together.

SpotOn® LR offers great flexibility as the system can be repositioned after initial installation and can be retrofitted at a specific location on above ground, buried or insulated pipe.

Used in combination with AUTO LR software based on baseline extraction and additional sequential statistical analysis (a unique feature of AUTO LR), spotOn® LR offers great improvement compared to any other screening or monitoring long-range solution available in the market:

- 10 times increase in sensitivity;
- Identification of anomalies at welds, supports or other features;
- Independent of operator skills.

Figures 4 show a comparison between the expected sensitivity performance using screening mode or a long range monitoring device from other vendors (Figure 4a) and the expected sensitivity using spotOn® LR (Figure 4b).

The graphs in Figures 4 report thresholds based on average values experienced in site applications. The X axis is the anomaly depth in the percentage of total wall thickness, while the Y axis is the Cross section Change of the pipe. The curves are traced for different pipe sizes. The graph is presented in a specific aspect ratio of the corrosion (5:1 ratio between corrosion length and corrosion depth). As the anomaly's aspect ratio decreases (for example 1:1) both the cross section and generally the detectability of the anomaly decreases.

U	AE	LR	U+LR	U+AE	AE+LR	U+AE+LR
INTERNAL CORROSION	LEAKS	INTERNAL CORROSION	LONG RANGE CORROSION + PRECISE THICKNESS VALUE	INTERNAL CORROSION + LEAKS + CRACKS	LONG RANGE CORROSION EXTERNAL OR INTERNAL + LEAKS + CRACKS	LONG RANGE CORROSION EXTERNAL OR INTERNAL + LEAKS + CRACKS + PRECISE THICKNESS VALUE
EROSION	CRACKS	EXTERNAL CORROSION				
SUBSTITUTE CORROSION COUPONS	STRESS CORROSION CRACKS					

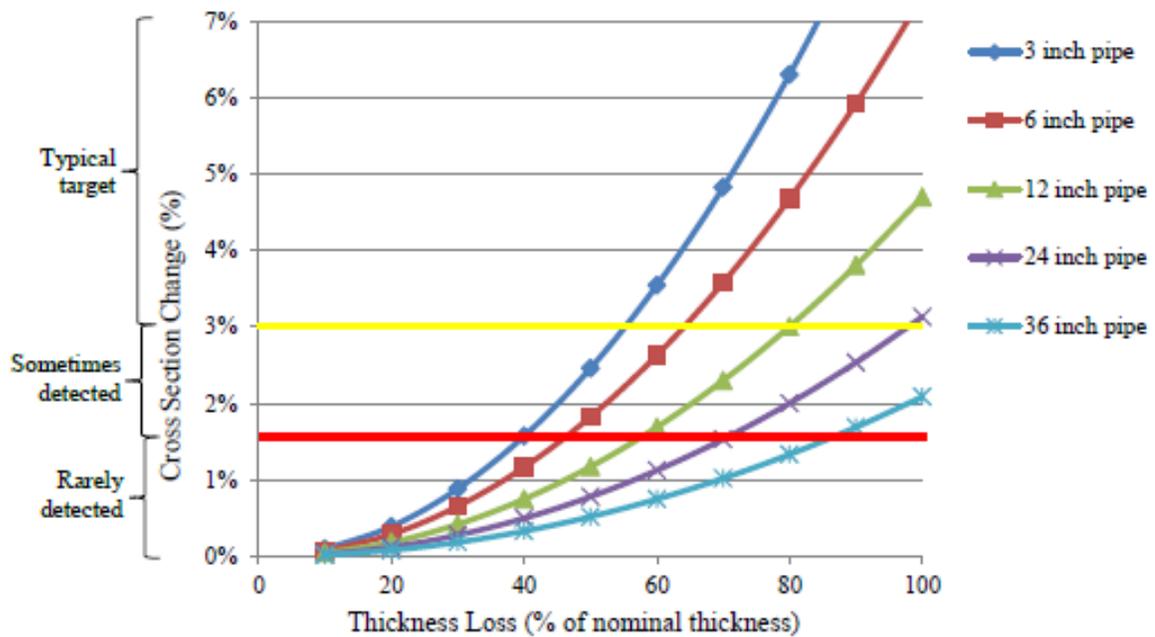


Figure 4a: Typical LRUT screening sensitivity when corrosion aspect ratio 5:1. Horizontal axis is the percentage thickness loss if compared to thickness in a healthy area. Values have been calculated for schedule 40 pipe below 12 inches and schedule 20 pipes above 12 inches. Typical target is 3% cross section loss. In some cases 1.5%-3% cross section loss can be identified. Corrosion defects below 1.5% cross section area rarely detected.

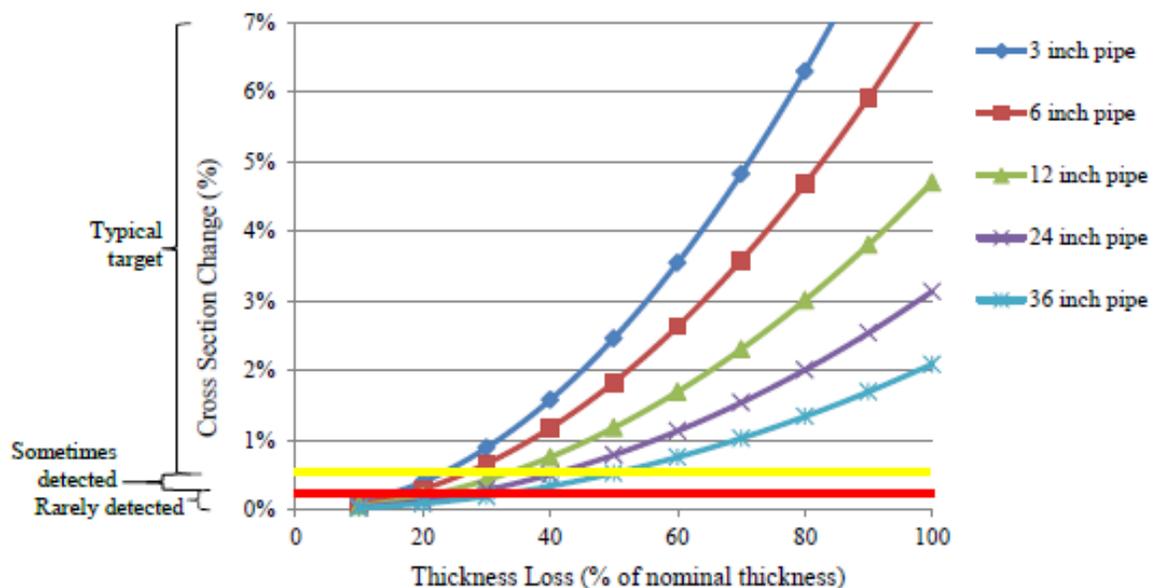


Figure 4b: Typical LRUT monitoring sensitivity when corrosion aspect ratio 5:1. Horizontal axis is the percentage thickness loss if compared to thickness in a healthy area. Values have been calculated for schedule 40 pipe below 12 inches and schedule 20 pipes above 12 inches. Typical target is 0.5% cross section loss. In some cases 0.25%-0.5% cross section loss can be identified. Corrosion defects below 0.25% cross section area rarely detected.

SpotOn® LR has some shortcomings:

- Does not measure direct wall thickness;
- Is not suitable to detect corrosion running along the length of the pipe;
- Has a rather large dead zone so that the area under the clamp is not inspected;
- Cannot detect very small pits (although sensitivity is greatly increased compared to screening).

The use of spotOn® U together with spotOn® LR enables to mitigate the first 3 of the shortcomings listed above while spotOn® AE (described below) would mitigate the issue of detectability of small pits. SpotOn® AE can be used to detect small pits developing a leak where both UT and LR failed to identify the growing corrosion pit.

c. SpotOn® AE

SpotOn® AE is a fast, accurate and reliable Acoustic Emission monitoring system that can identify leaks in a pipeline as well as cracks and third party interference. SpotOn® AE is deployed on pipes using the same setup described for spotOn® U. The capability of spotOn® AE to detect leaks is important when localized pitting is a possible damage mechanism. Relatively small through thickness pits not detectable with spotOn® U or spotOn® LR generating a loss of containment would, therefore, be detected using spotOn® AE and alarms are quickly sent to the asset owners in order to avoid major incidents.

SpotOn® AE is also used to monitor for Stress Corrosion Cracks (SCC). As cracks develop, these emit some noise that can be detected using spotOn® AE. As SCC is a major threat in several alloys used in critical onshore and offshore installations as well as some buried pipeline locations, spotOn® AE offers a solution for monitoring such locations 24/7.

Figures below shows an example of Leak monitoring using spotOn® AE

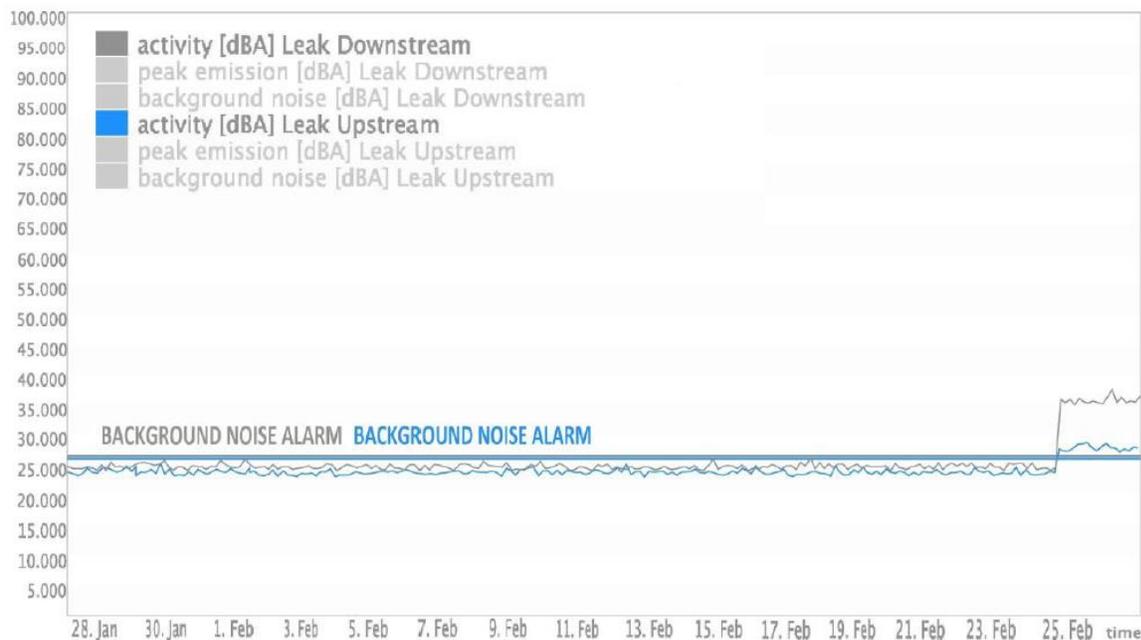


Figure 5

III. CONCLUSIONS

- Cost reduction is currently the foremost issue on the agenda of every oil and gas company management team. The standard practice of continuous inspection campaigns in oil and gas installations using approaches that are less than precise and expensive may not achieve the final target of reducing risks and might, by virtue of having personnel involved on site every day, increase errors and risk. Monitoring offers the opportunity to reduce costs while reducing risks, therefore, being the best choice both for management and integrity engineers;
- Monitoring using corrosion probes (ER or coupons) is very limited in its effectiveness as one must assume that the corrosion effect of process fluid on the probe is the same of the structure being monitored. 50 years of experience in the industry reveal that this may not be the case. Also, these probes are intrusive and managing them increases costs and risk of failures;
- A3 Monitoring offering of integrated monitoring whereby several monitoring technologies are used together is both unique and the most appropriate technical approach. Using technology integration detection range is optimized, target issues are safely and timely identified and the cost is greatly reduced.
- A3 Monitoring plug-and-go spotOn technology immensely reduces the implementation effort compared to any other monitoring solution available in the market. It is possible to implement spotOn® literally within 24 hours since deciding to implement corrosion monitoring at a specific location.
- Installed at several oil and gas facilities in more than 10 countries worldwide, spotOn® technology offers the most advanced, reliable and cost-effective solution in the monitoring market.

For more information on the capabilities of the **spotOn® System** please contact NVI, LLC at:

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