March 2016

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Pipeline Leak Detection ...

Dr. Klaus Ritter
Editor in Chief

... is inevitable for a safe and economic pipeline operation. New Technologies are constantly being developed

Dear Reader,

The transportation of fluids and gases in pipelines is still increasing all over the world and with very good reason: Pipelines are the safest and most economical transportation systems for long distances. It is important to make sure that both, new and already existing pipelines always make use of state-of-the-art technology, in order to run pipelines safely, cost effectively and to extend their life cycle.

The exchange of existing experiences from all over the world is necessary to create and distribute such state-of-the-art technology. The electronic **Pipeline Technology Journal (ptj)** delivers essential information about the industry's latest developments and most important discussions.

We are constantly advancing the Pipeline Technology Journal to meet the information needs of pipeline professionals worldwide. After increasing our frequency of publication from two to six issues a year, we are now setting the technical focus of each ptj edition to an important field of work within the pipeline industry. This issue will focus on Pipeline Leak Detection and Monitoring. The next edition in May, prior to the ptc, will focus on Planning and Construction. You can check out all editions main areas on our **media kit.**

The Pipeline Technology Journal is taking another important step forward and will be available as Chinese Edition from mid-April on. With this edition we are selectively aiming at the growing pipeline market in the People's Republic of China. Thus, we enable international pipeline experts and companies to introduce their solutions and to promote their products and services to a great market which offers rich potentials.

But we are not finished with our development. We have inspired initial discussions with other potential partners for further editions of ptj, for example in Iran. The harmonization between the Islamic Republic of Iran and the western world enables us to animate an active exchange between the Iranian newcomers and the global pipeline community.

As you can see, we will never get tired of pushing the pipeline community's constant exchange. We will never get tired of inviting you to the next Pipeline Technology Conference as well. From 23 – 25 May 2016, the 11th ptc again will bring together pipeline experts from all over the world.

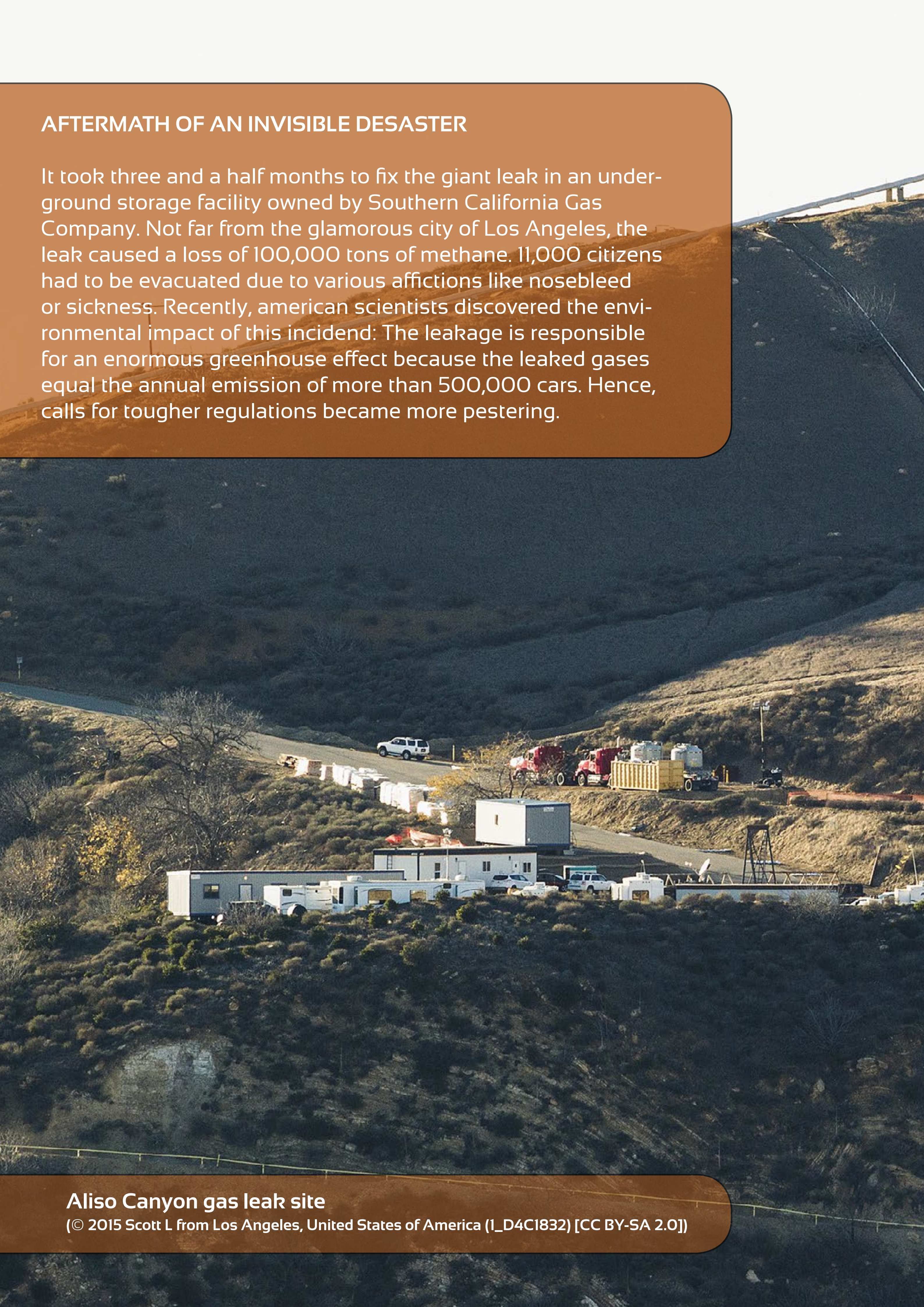
Get involved! Participate in the professional exchange during the Pipeline Technology Conference. Take the chance to talk about your experiences, to report about your challenges and to exchange with many colleagues from 55 different countries.

Yours,

> Dr. Klaus Ritter, Chairman of the ptj Editorial Board / ptc Advisory Committee

AFTERMATH OF AN INVISIBLE DESASTER

It took three and a half months to fix the giant leak in an underground storage facility owned by Southern California Gas Company. Not far from the glamorous city of Los Angeles, the leak caused a loss of 100,000 tons of methane. 11,000 citizens had to be evacuated due to various affictions like nosebleed or sickness. Recently, american scientists discovered the environmental impact of this incidend: The leakage is responsible for an enormous greenhouse effect because the leaked gases equal the annual emission of more than 500,000 cars. Hence, calls for tougher regulations became more pestering.



Aliso Canyon gas leak site
(© 2015 Scott L from Los Angeles, United States of America (1_D4C1832) [CC BY-SA 2.0])

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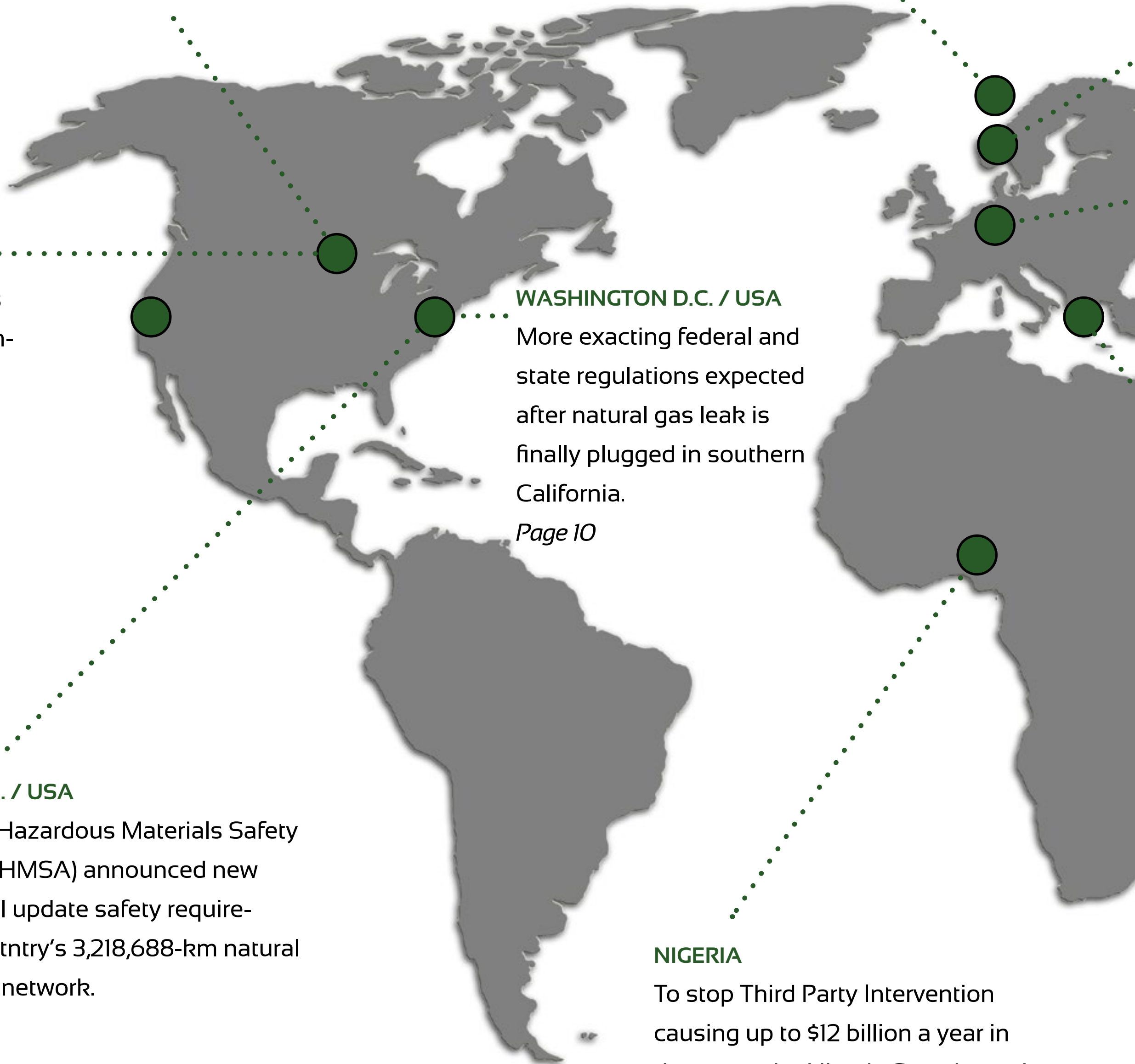

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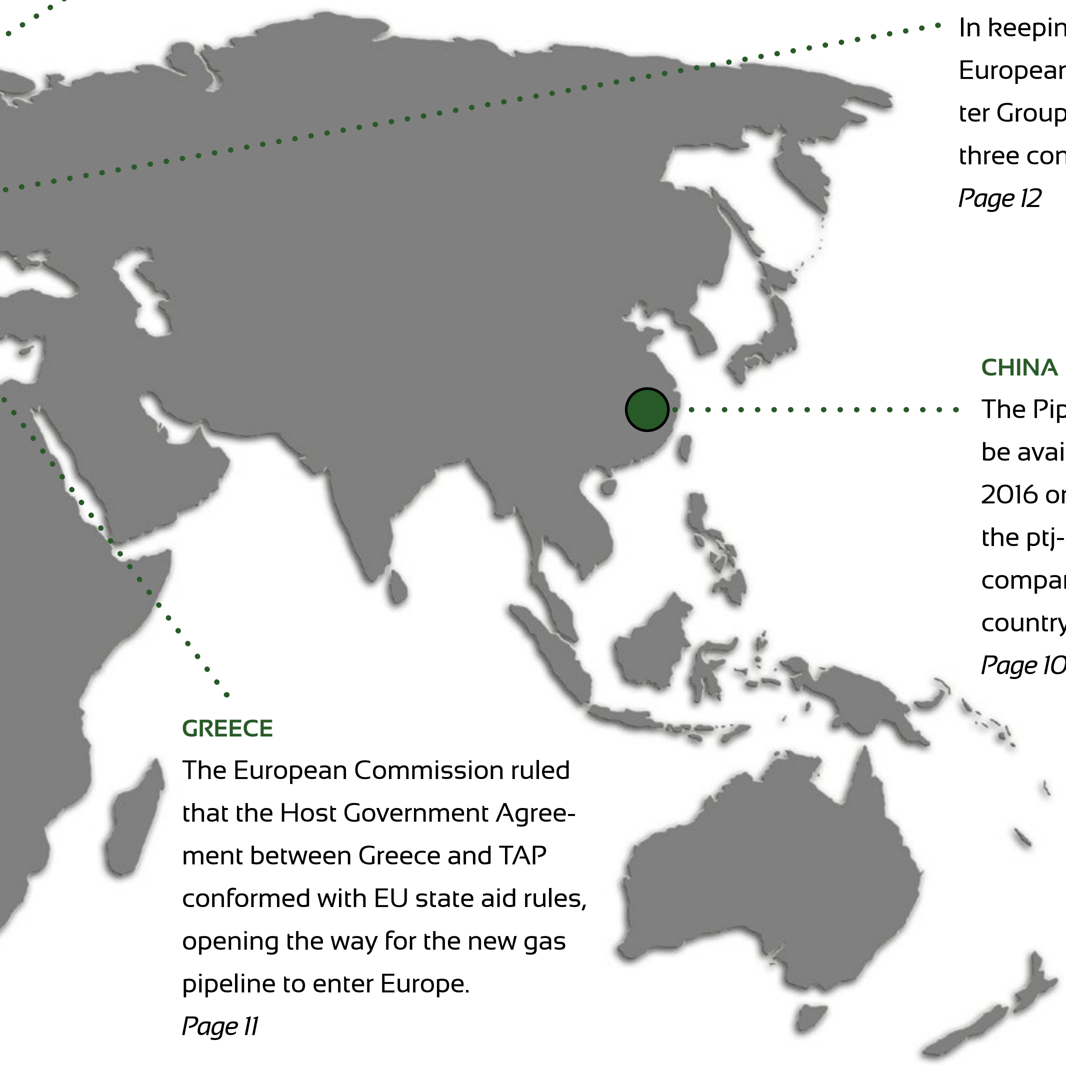

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CHINESE EDITION OF PIPELINE TECHNOLOGY JOURNAL TO BE PUBLISHED IN APRIL FOR THE FIRST TIME

The Pipeline Technology Journal (ptj) will be available as Chinese edition from April 2016 on. This has been agreed between the ptj-publisher and a Chinese partner company associated with PetroChina, the country's biggest oil and gas group.

"It is our strong belief that the Chinese market is of greater importance for many international companies. Therefore, a closer cooperation and a translated edition of ptj is an appropriate step in building bridges between the Chinese pipeline industry and the global pipeline community", said Dr. Klaus Ritter, publisher and editor-in-chief of the Pipeline Technology Journal and also Chairman of the Pipeline Technology Conference (Berlin, 23 – 25 May 2016).

ptj China will be available from mid-April on. It will be released three weeks after the English edition. The final contract will be signed during the INTERPIPE 2016 in Lang Fang, China, taking place on 12 - 14 April 2016.

"This cooperation will enable foreign companies to introduce their Know-How to the Chinese market, and to advertise their products. We will reach up to 20,000 Chinese pipeline professionals with the Chinese edition of ptj. This includes operators, service and technology providers, government officials as well as media contacts", said Zhengtao Ma, General Manager of the partner company Langfang International Pipeline Conference & Exhibition Co. Ltd and responsible for the distribution of ptj China.

With this cooperation, the Pipeline Technology Journal will significantly extends its range to approximately 50,000 pipeline experts worldwide.

MORE EXACTING FEDERAL AND STATE REGULATIONS EXPECTED AFTER NATURAL GAS LEAK IS FINALLY PLUGGED IN SOUTHERN CALIFORNIA

Months after high levels of methane gas were detected leaking from a storage facility owned by Southern California Gas Company (SoCal Gas - the nation's largest natural gas distribution utility) in Aliso Canyon, the California Department of Conservation has declared that the leak has been permanent sealed with concrete.

The South Coast Air Quality Management District and the California Air Resources Board will continue to monitor the air in the coming weeks, looking at the levels of methane, mercaptans, benzene and hydrogen sulfide. Meanwhile, no more gas will be injected into the underground reservoir until all of the 114 remaining wells are inspected using new standards.

Rep. Brad Sherman (D-Porter Ranch) called for "tough new regulations" for the other 114 injection wells at the 3,600-acre underground natural gas storage facility, which is among the nation's largest. The gas company has said that many of those wells are aging, corroded and mechanically damaged.

6500 area residents who were forced to leave their homes in the wake of the leak will now be able to return. SoCal Gas will reimburse these residents for expenses incurred through relocation and the company expressed its readiness to work with state regulators in enhancing the security of the remaining wells in the Aliso Canyon storage facility.

Available from mid-April on: the Chinese Edition of ptj

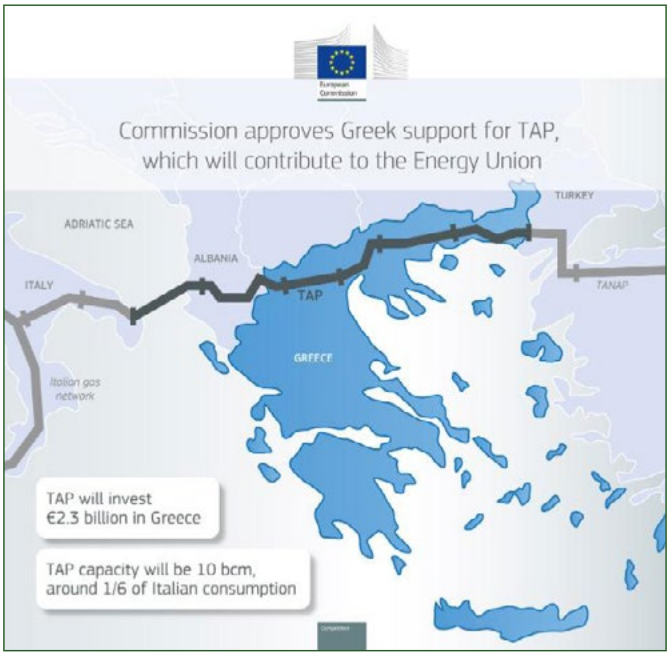
ROAD IS CLEAR FOR TRANS ADRIATIC PIPELINE TO EUROPE

Coinciding with the Trans Adriatic Pipeline (TAP) awarding of contracts last week for the engineering, procurement and construction (EPC) of approximately 760 km of cross-country onshore pipeline in Greece and Albania, the European Commission ruled that the Host Government Agreement between Greece and TAP conformed with EU state aid rules, opening the way for the new gas pipeline to enter Europe.

In particular, the agreement provides TAP with a specific tax regime for 25 years from the start of commercial operations. This may give the company an economic advantage over its competitors, who would not benefit from the specific tax regime, and therefore involves state aid in the meaning of the EU rules.

Maroš Šefčovič, Vice-President responsible for Energy Union, said: "Today's approval of the TAP agreement is an important step towards completing the Southern Gas Corridor. The Energy Union framework strategy of February 2015 identified this project as a key contribution to the EU's energy security, bringing new routes and sources of gas to Europe. Just on Monday, the Southern Gas Corridor ministerial meeting in Baku, which I attended, confirmed the determination of all participating countries and consortia to complete this key infrastructure project in time."

The EU ruling is a key factor in enabling further work on the TAP pipeline to proceed. Thus, one of the EPC contracts was awarded to a joint venture comprised of Bonatti S.p.A (Italy) and J&P AVAX S.A (Greece) for two lots in northern Greece. The sections cover approximately 360 km of pipeline, stretching between Kavala and Ieropigi (Albanian border). The other to SPIECAPAG (France) for a 185 km lot in Greece, between Kipoi and Kavala, as well as two lots in Albania (215 km in total), stretching from Bilisht to Topoje. SPIECAPAG will also carry out the pipeline river crossing at the Greek-Turkish border, where TAP will be connecting to the Trans Anatolian Pipeline (TANAP).



PHMSA WITH A NEW PROPOSAL FOR U.S. PIPELINE OPERATORS TO PROACTIVELY MANAGE PIPELINE INTEGRITY

In the wake of a number of recent high-profile pipeline gas leaks / explosions in the United States and resulting uncertainty among U.S. pipeline operators over the status of more stringent measures to regulate their activity, the Pipeline and Hazardous Materials Safety Administration (PHMSA) announced new proposals last week that will update safety requirements for the country's 3,218,688-km natural gas transmission network. According to PHMSA the proposed rules provide pipeline operators with regulatory certainty, and responds to both Congressional mandates and outside safety recommendations for pipeline operators to proactively manage pipeline integrity matters.

"The significant growth in the nation's production, usage and commercialization of natural gas is placing unprecedented demands on the nation's pipeline system," said U.S. Transportation Secretary Anthony Foxx. "This proposal includes a number of commonsense measures that will better ensure the safety of communities living alongside pipeline infrastructure and protect our environment."

In particular, the proposed changes to gas transmission safety regulations are expected to result in fewer incidents, which could lead to a reduction in gas released into the atmosphere as greenhouse gases (GHG). The proposed rule is expected to result in net annual average reductions of 900-1,500 metric tons of carbon dioxide and 4,600-8,100 metric tons of methane, a powerful greenhouse gas. The rule also proposes changes to the way that pipeline operators secure and inspect gas transmission pipeline infrastructure following extreme weather events, such as hurricanes and flooding.

- The PHMSA's proposal would moreover revise and strengthen federal Pipeline Safety Regulations by:
- Modifying repair criteria for pipelines inside and outside of high consequence areas,
- Providing additional direction on how to evaluate internal inspection results to identify anomalies,
- Clarifying requirements for conducting risk assessment for integrity management, including addressing seismic risk,
- Expanding mandatory data collection and integration requirements for integrity management, including data validation and seismicity,
- Requiring additional post-construction quality inspections to address coating integrity and cathodic protection issues,
- Requiring new safety features for pipeline launchers and receivers, and Requiring a systematic approach to verify a pipeline's maximum allowable operating pressure (MAOP) and requiring operators to report MAOP overruns.

SALZGITTER GROUP PROFITS FROM REBOUNDING NATURAL GAS MARKET IN EUROPE

In keeping with the current upswing in the European natural gas market, the Salzgitter Group has announced the award of three contracts by Open Grid Europe for approximately 70,000 tons of spirally-welded large-diameter pipes.

The pipes will be used in the extension of the natural gas grid in southern and western Germany, enhancing the security of supply.

The orders were booked by the Group's subsidiary Salzgitter Mannesmann Großrohr GmbH (MGR) and will be produced in Salzgitter.

Together with other pipeline projects in France, Poland and Italy totaling more than 50,000 t, double-shift capacity utilization has been secured for the large-diameter pipe mill through to mid-2017. Salzgitter Flachstahl GmbH is to supply the input material.

The companies of the Salzgitter Mannesmann Röhrenwerke Group as a leading producer of high quality line pipes are set to benefit from this trend.

NORWAY WEIGHING GAS PIPELINE OPTION FROM THE BARENTS SEA TO CONTINENTAL EUROPE

Norway, Europe's biggest supplier of natural gas after Russia, is seeking a signal from the European Union regarding the future role of its gas within the European energy mix.

Cognizant of the potentially gigantic reservoirs of gas in the Barents Sea and of the huge investments it would require to bring this commodity to market, Norway is looking for a clear statement next week stating that the fuel can play an important role in reducing emissions and to focus on the need for new infrastructure, Norwegian Petroleum and Energy Minister Tord Lien said Friday.

Further: "A considerable share of our untapped gas resources are located in the Barents Sea. Additional gas export capacity from the Barents Sea will be decided during the next decade. This future expansion can either be an expansion of the LNG capacity with destination flexibility, or a pipeline connection to Europe. Such expansion demands very substantial up-front investments. Companies investing in this capacity will make their choice on a commercial basis, taking into consideration the prospects for gas in Europe."

At an EU-Norway energy conference in Brussels last week, Climate Action Commissioner Miguel Arias Canete said natural gas will remain an important part of the EU's energy mix, calling Norway a trusted and stable partner.

Salzgitter Group awarded three contracts by Open Grid Europe for around 70,000 t of spirally-welded large-diameter pipes (© 2016 Salzgitter Group)

NDT GLOBAL WINS MULTI-MILLION EURO STATOIL CONTRACT IN FACE OF KEEN COMPETITION

NDT Global, a leading supplier of ultrasonic pipeline inspection and integrity services, has announced that it has received a multi-million euro contract, on behalf of Gassco, from Statoil, Norway's leading gas and oil enterprise.

In close collaboration with Statoil, NDT Global is developing a suitable inline inspection (ILI) tool for the 707 km, 24-42 inch Åsgard Transport gas pipeline. The company will also supply the in-line inspection tool to perform the corresponding survey. This particular tool includes the latest in-house developments of combined inspection technologies.

The Åsgard transport pipeline starts at the semi-submersible Åsgard B platform in the Norwegian Sea, and terminates at the Kårstø processing plant in southwest Norway. It has been in operation since October 2000.

NDT Global has worked with Statoil in the scope of a Framework Agreement since 2006. The current purchase order was received in 2015 and in-line inspection is scheduled to commence in 2017.

Asgard B Platform (all rights on this picture by Statoil)

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www.pipeline-journal.net
ptj@eitep.de

Publisher
Euro Institute for Information and Technology Transfer GmbH
Am Listholze 82
30177 Hannover, Germany
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Editor in Chief
Dr. Klaus Ritter
E-Mail: ritter@eitep.de
Tel: +49 (0)511 90992-10

Editorial Board
Advisory Committee of the Pipeline Technology Conference (ptc)

Editorial Management & Advertising
Design & Layout
Admir Celovic
E-Mail: celovic@eitep.de
Tel: +49 (0)511 90992-20

Editorial Staff
Dennis Fandrich: fandrich@eitep.de
Mark Iden: iden@eitep.de

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NIGERIA EMPLOYING SOPHISTICATED DRONES TO PREVENT ONGOING SABOTAGE TO NATIONAL PIPELINE INFRASTRUCTURE

With no apparent stop to Third Party Intervention causing up to $12 billion a year in damages to the country's pipeline infrastructure in Nigeria, the Nigeria Security and Civil Defense Corps (NSCDC) has established a 'Command and Control Center' to monitor the national grid in the South-South region and preempt vandals before they rupture the lines and steal the oil.

Emmanuel Okeh, spokesman of the Corps, said the "NSCDC as the lead agency in the protection of critical infrastructure has put a lot of technology in place to ensure the successful tracking of vandals and possibly to bring the act to the barest minimum." Over 100 personnel have been trained in the use of drones for pipeline monitoring. The new drones use GPS to document the times and places where vandals were observed.

In addition to the monetary losses, the business of breaching pipelines and stealing the product has exacted an enormous human and environmental toll: The National Nigerian Petroleum Corporation (NNPC) has said a total of 350 persons including NNPC staff, police officers and community members have been killed as a result of the activities of the oil thieves; while Shell has noted that the sabotage of oil pipelines is the major cause of spills and pollution in the oil-producing southern portion of Nigeria.

To further bolster the efforts of the NSCDC, Gracious Omatseye, National Chairman of Nigerian Institution of Electrical Electronic Engineers (NIEEE), has advised the government to engage all stakeholders in oil and gas pipeline host communities: "The introduction of an annual award to communities with less or no records of destruction of oil pipelines or electricity installations would go a long way in encouraging community leaders to ensure that pipelines and installations were not destroyed."

TRANSCANADA CLINCHES MEGA DEAL WITH COLUMBIA PIPELINE GROUP TO BECOME A FORCE IN THE GLOBAL GAS MARKET

TransCanada confirmed rumors reported in these pages last week that the company will acquire Houston-based Columbia Pipeline Group and its 24,000-km pipeline network for $13 billion, creating one of the largest regulated natural gas transmission businesses in North America.

Russ Girling, TransCanada's CEO, said adding Columbia's operations will create a 91,000-km natural-gas-pipeline system connecting the most prolific supply basins in the Marcellus and Utica shale gas regions of the United States to markets across the continent. It will also be positioned to feed liquefied natural gas terminals for export to international markets.

Moreover, he said that the combined company will have $23-billion (Canadian) of near-term projects secured by long-term contracts or regulated cost-of-service revenue that will support, or even increase, TransCanada's target of 8-per-cent to 10-per-cent dividend growth a year through 2020.

Russ Girling, CEO of TransCanada

TRANSCANADA MOVES FORWARD WITH PLANS TO CONSTRUCT NEW 1600 KM CRUDE OIL PIPELINE EXTENSION OF THE MAMMOTH ENERGY EAST PIPELINE PROJECT

TransCanada, looking to begin construction on the additional 1600 km crude oil extension of the Energy East Pipeline, has signed a provisional multimillion - dollar order with ABB Canada for the development of 22 electrical houses (e-houses) along the pipeline route which would supply electricity to the pipeline's pumping stations.

The $15.7-billion Energy East pipeline would carry a million barrels a day of western crude as far east as Saint John to serve domestic refineries and international customers.

Opposition to Energy East is mounting among nearby mayors on environmental grounds. The National Energy Board – and ultimately federal cabinet – has the authority to approve Energy East. But as witnessed in British Columbia, strong opposition from provincial and local governments can erect significant hurdles for crude pipeline projects.

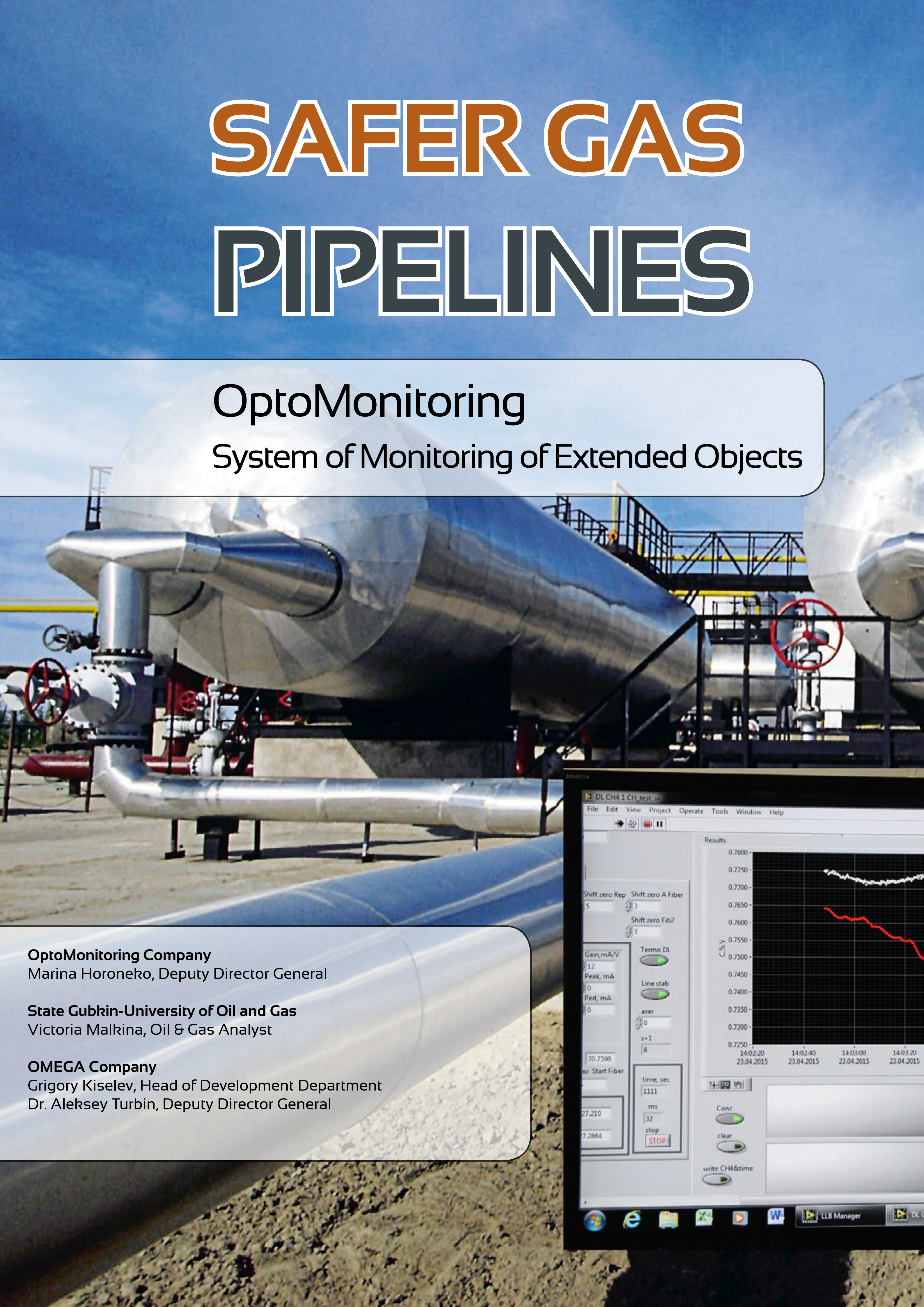
If the government gives its ok, TransCanada has said it could begin construction by 2018. The pipeline would be ready for use by 2020.

Energy East Pipeline route map (© 2015 TransCanada)

SAFER GAS PIPELINES

OptoMonitoring

System of Monitoring of Extended Objects



OptoMonitoring Company
Marina Horoneko, Deputy Director General

State Gubkin-University of Oil and Gas
Victoria Malkina, Oil & Gas Analyst

OMEGA Company
Grigory Kiselev, Head of Development Department
Dr. Aleksey Turbin, Deputy Director General

ABSTRACT

It is generally acknowledged that the protection of pipelines against technological, ecological and anthropogenic damage has specific features depending on the transported hydrocarbon. Taking into consideration this fact and possessing considerable experience in elaborating fiber-optic monitoring systems for the energy branch in 2015 the Moscow-based PetroLight Company launched the OptoMonitoring project aimed at production of a specialized monitoring system for gas pipelines. Like other PetroLight products the System of Monitoring of Extended Objects (OptoMonitoring SMEO) is based on the implementation of distributed fiber-optic sensors as far as a series of additional devices required for better event tracking and recognition on gas pipelines.

In 2010 in cooperation with the Transneft Company, world's biggest oil and oil products transporter, PetroLight created the OMEGA Company through which more than 5500 kilometers of pipelines have been equipped with the fiber-optic Leak Detection and Activity Control System (OMEGA LDACS). The new SMEO option is the immediate result of the interest of the GAZPROM Company in systems which for years have been proving their effectiveness on oil and oil products` pipelines.

Strictly speaking the principal difference between the leak detection on pipelines transporting liquids and gas is the Joule-Thomson effect which describes the intensive temperature change of a gas when it is forced through a valve or porous plug while kept insulated so that no heat is exchanged with the environment. The aforementioned brought attention to the Distributed Acoustic Sensing (DAS) application in monitoring systems designed for gas pipelines: according to the OMEGA-PetroLight ideology the sensing methodology is thought to confirm the leakage signal obtained from the Distributed Temperature Sensing.

THE SMEO OPERATION FEATURES

The OptoMonitoring SMEO allows the operator inspecting temperature, acoustic vibration and strain along the cable. Additionally SMEO has an option to deploy Fiber Optic Methane Annunciator (FOMA) which inspects real time methane concentration at locations of particular interest.

System's operational principle is based on the use of fiber optic cable as a linear sensor, where a narrow pulse of light is sent into the cable and the resulting backscatter is measured. The fiber optic cable is buried into the ground along a pipeline or an extended object. Regular SMEO components are the Logical Module (LM), Fiber Optic Cable (FOC), Calculation Server (CS) and Automated Operator Workstation (AOW).

The LM sends laser pulses through the FOC. The information about temperature, vibration or strain along the FOC travels back to the LM where it is interpreted. Further, the interpreted signal is sent to the CS where the signal is processed. Processed signal is sent to the AOW and the operator takes a decision based on the nature of the event detected.

THE OPTOMONITORING SMEO DETECTION TECHNOLOGY

OptoMonitoring SMEO uses up to three measuring techniques simultaneously: Distributed Acoustic Sensing (DAS), Distributed Temperature Sensing (DTS) and Distributed Strain Sensing (DSS).

When a near infrared light pulse of 1550 nm enters the FOC, environmental variables such as temperature, pressure and strain can affect the FOC's light transmission characteristics and cause portions of light to backscatter. Backscattered light is further separated into various wavelengths – Rayleigh, Raman and Brillouin bands. This separation is also due to different interaction mechanisms between the light pulse and the FOC.

Distributed Acoustic Sensing uses Rayleigh wavelength analysis for acoustic and vibration detection. As seen in Figure 2 the main backscattered wave is at the wavelength of the launched pulse and is called the Rayleigh band. The nature of this scattered light is affected by small strain events within the optical fiber structure, which themselves are determined by the localized acoustic or seismic environment. Rayleigh scattering is characterized by interaction between light and particles (atoms and molecules) which are smaller than the wavelength of light. In Rayleigh scattering the particles can scatter light radiation elastically without light energy change.The intensity of the reflected light is measured as a function of time after transmission of the laser pulse. When the pulse has had time to travel the full length of the fiber and back, the next laser pulse can be sent along the fiber. Changes in the reflected intensity of successive pulses from the same region of fiber are caused by changes in the optical path length of that section of fiber. The velocity of light propagation in the FOC is easily determined and since the intensity of the backscattered light decays exponentially over time the distance is calculated from the time travel of backscattered light. DAS measurement is performed by recording the returning signal as a function of time and thus defining the acoustic field all along the FOC.

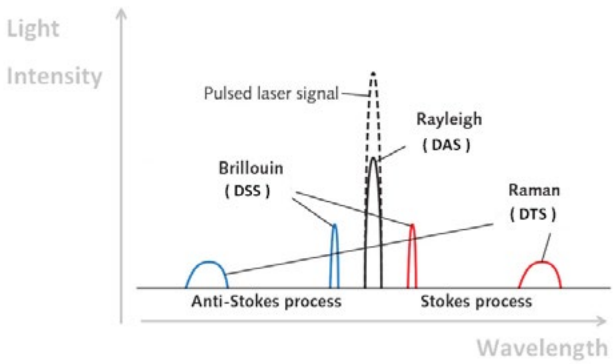


Figure 2: The scattering paradigm implemented in SMEO

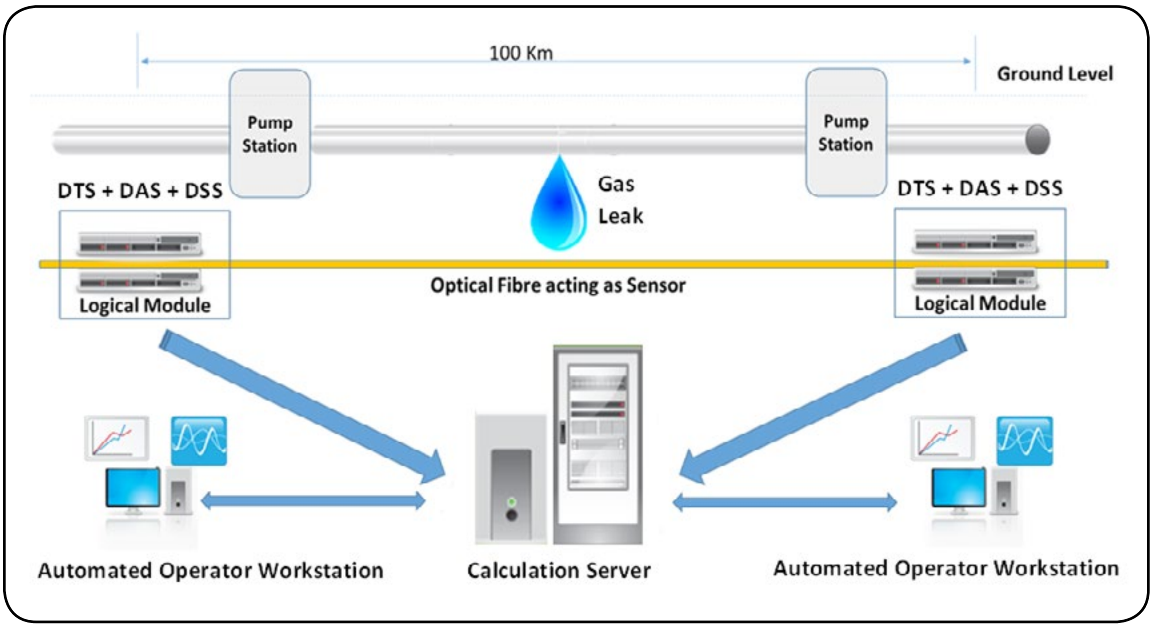


Figure 1: The SMEO operation procedure

Distributed Temperature Sensing uses Raman wavelength analysis for temperature measurement. When the FOC gets exposed to thermal effects, lattice oscillations within the fiber are induced. Once laser pulse passes through these thermally excited molecules, an interaction takes place between photons and fiber's molecules. The interaction is molecule vibration and it depends on temperature of the FOC. The Raman scattered light has two components that lie symmetric to the Rayleigh peak: the Stokes peak and Anti-Stokes peak. The intensity of the Anti-Stokes peak is lower than that of the Stokes peak, but it is strongly related to temperature; whereas the intensity of the Stokes peak is only weakly related to temperature. By calculating a ratio of the Anti-Stokes to Stokes signal intensities, an accurate temperature measurement can be obtained. Combining this temperature measurement technique with distance measurement through time-of-flight of light, the DTS provides temperature parameters incrementally along the entire length of the FOC.

Distributed Strain Sensing uses Brillouin wavelength analysis for mechanical strain detection in extended objects. Deformation of the FOC, such as strain, will cause a change in the fiber's refractive index - a carrier-deformation wave which is also a form of sound wave. When a laser pulse travelling along the FOC interacts with the aforementioned crystalline lattice waves, the light is diffracted backward, giving rise to a frequency-shifted component by a phenomenon similar to the Doppler shift. Thus the Brillouin scattering is the result of the interaction between optical and sound waves in optical fibers. Like Raman scattering the Brillouin scattering is inelastic.

As opposed to distributed sensors, FOMA uses a point-type sensor and is intended for remote detection of threshold methane gas concentration, using the FOC for signal delivery. The principle of FOMA operation is based on self-tuning and continuous monitoring of real-time methane concentration in a measuring cell. The FOMA takes advantage of the light absorbing properties of the gas. When a laser pulse enters the methane detection cell, it is absorbed by the methane gas. Cell's near-IR laser diode operates at methane's molecule absorption wavelength of 1650 µm. By comparing the amount of light returning from the detection cell to the amount of light passing through the calibration cell, quantitative measurement of gas concentration is performed. With the weight of 0.2 kg the FOMA sensitive element is able to detect methane with the precision of 200 ppm. The distance from the element and the LM can be up to 50 km, no electricity is required for this sub-system.

Besides SMEO, methane detection using reliable sensors is one of the most important safety issues for chemical facilities, gas plants, mines, pipelines and other high risk installations. Being the dominant component of natural gas, methane has the LEL (Lower Explosive Limit) of 4.4% which makes the gas inflammable and explosive. Unfortunately methane explosions occur regularly and lead to the fatal accidents. Several sites of methane detection are actual for FOMA implementation, among them are pipeline transition and passage zones, pipeline crossing zones with railways, roads and underwater passages. One SMEO LM can host over 200 FOMAs, which monitor real-time methane concentration with extremely high sensitivity, alerting a facility operator before dangerous concentrations are reached.

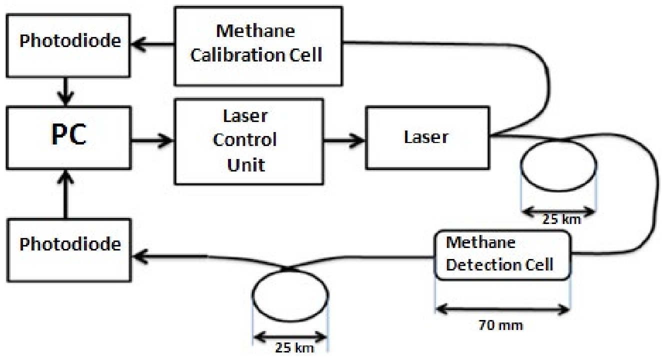


Figure 3: The FOMA scheme

THE SMEO PRINCIPAL EQUIPMENT

A regular OptoMonitoring SMEO component is the Fiber Optic Cable (FOC). A glass optical fiber is made of fused silica and used for transmitting light over large distances with very small losses. It consists of optical fiber, inert gas, steel module, aluminum shell, armored steel and polymer coating. The optical fiber is the part which transmits the light and it has outer diameter that can be as small as 5 to 10 micrometers. Such fiber has strains surrounded by cladding. The cladding made of silica with slightly lower index of refraction than the core. The purpose of the cladding is to keep the light in the core (e.g. by total refraction), minimize the losses, and also physically to support the core region as the light propagates in the fiber. The optical fiber is surrounded by an inert gas. The purpose of the inert gas serves to protect the optical fiber from hydrogen gas, which can lead to fiber darkening upon contact. Layers of steel, aluminum and armored steel provide protection, robustness and rigidity to the FOC. Finally the coating applied to prevent steel oxidation. Depending on the particular project or application of SMEO, the coating can be made of acrylate, in some cases of polyimide, and for some special application (e.g. harsh environments, high temperatures) of other materials (e.g. carbon, aluminum, gold, etc.).

The light used for sensing purposes in the core of the optical fiber does not interact with any surrounding electromagnetic field. Consequently, the fiber optic sensors are intrinsically immune to any EM interference (EMI), which contributes significantly to their long-term stability and reliability. The ability to measure over distances of several tens of kilometers without the need for any electrically active component is an important feature when monitoring large and remote structures, such as landmark bridges, dams, tunnels, and pipelines. The optical fiber operating at a wavelength of 1550 nanometers can be used for both sensing and signal transmission purposes.

The LM serves as a core of the SMEO and is a specialized optoelectronic device, ensuring the generation, real-time reception and pre-processing of optical signals. The LM operates in real-time mode by a set of given algorithms and performs data collection functions from the FOC, primary data processing, and transmission to the CS. LM consists of several components inside a shielded cabinet, such as DAS, DTS, DSS and FOMA modules in addition to a KVM-switch, patch panel and a UPS. The CS is SMEO's datacenter and ensures real-time reception LM signals, processing, interpretation and forwarding of ready-made information for an AOW operator.

Additionally it serves for data storage, collecting and saving all events that occurred along an extended object. The AOW gives control over SMEO to the operator. The AOW displays information about possible activities along an extended object, provides map services and event information for the operator, gives access to CS database and can be used to perform SMEO maintenance operations.

Figure 4: The OptoMonitoring Logical Module (on the left)

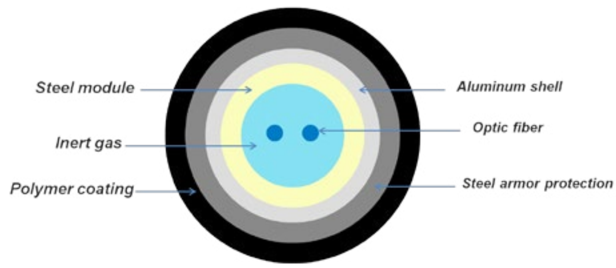


Figure 4: The OptoMonitoring Logical Module (on the left)

THE SYSTEM PERFORMANCE

OptoMonitoring SMEO enables the gas pipeline operator to perform leak detection. The DTS performs the automatic detection of temperature change of 1°C on a 5 meter cable sensor section which is a part of a 50 km length controlled by a LM.

Impact detection accuracy along the distributed sensor, m	± 5
Sensitivity of phase change, radian	0.1 – 0.2
Range of analyzed frequencies, Hz	1–500
Pulse recurrence, kHz	1
The pipeline length controlled by one module of the system, km	100

Table 1: The SMEO DAS parameters

In addition to leak detection capabilities, SMEO DAS serves as a security tool for extended objects. OptoMonitoring SMEO prevents illegal tie-ins (which is not very common in the case of high pressure gas pipelines), intrusions and trespassing, as it performs real time monitoring of vibration activities along the extended object. An important advantage of the SMEO DAS is not only the event signal delivery from a protected area, but also the determination of the signals' nature. The operator receives a notification when the system has recorded potentially dangerous activities such as pedestrian movement, excavation works by entrenching tool, excavation works by trencher, light and heavy vehicle movement as far as 10 meters from the pipeline.

Spatial resolution along the distributed sensor, m	5
Strain accuracy, με	10
Strain range, %	-1.25 to 1.25
The pipeline length controlled by one module of the system, km	50

Table 2: The SMEO DSS parameters

Optomonitoring SMEO DSS performs structural duty and guards pipeline integrity. Ground movement, soil collapses, hydraulic erosion, unstable slopes, earthquakes, fatigue cracking during pipe shipment or manufacturing flaws put stress on the pipeline in critical areas, producing pipeline displacement or metal deformation that may cause the pipeline to fail. Before critical failure can occur, mechanical pipe displacement will exert strain on the attached FOC, thus alerting the system operator.

CONCLUSION

Thus the Optomonitoring SMEO based on a variety of technical solutions provides a broad range of monitoring procedures required for technologically and ecologically safer gas transportation. Among new options to be integrated into this control and measuring complex is for example the system of monitoring of electrical installations on oil and gas pipelines which is now finalized by the Omega and OptoMonitoring scientists. The system is based on continuous temperature change measurement with the DTS and will exclude possible fires caused by contact disturbances.

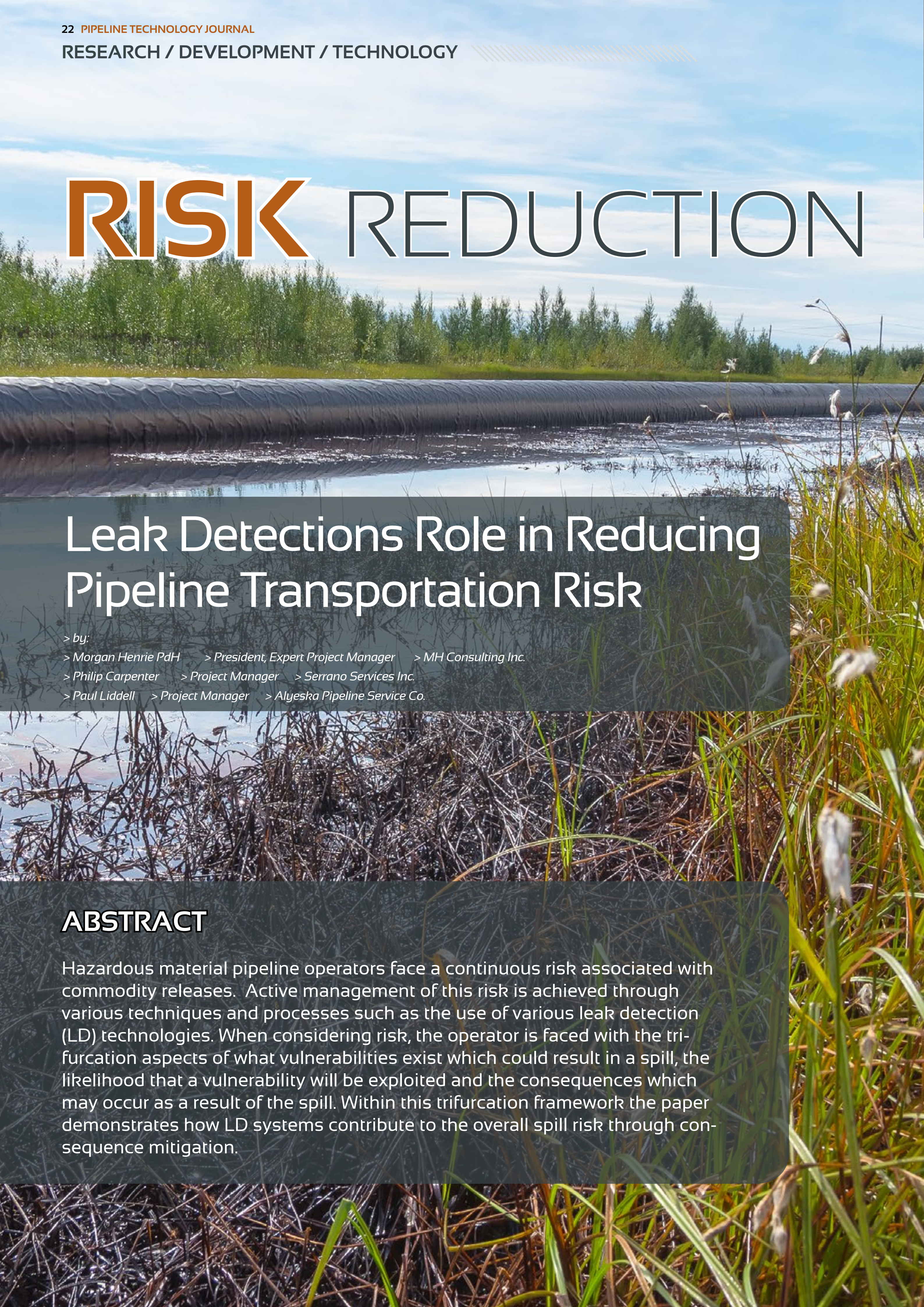
Authors

Marina Horoneko
OptoMonitoring Company
Deputy Director General
Horoneko@optomonitoring.ru

Victoria Malkina
State Gubkin-University of Oil & Gas
Oil & Gas Analyst
bg@ecovestnik.ru

Grigory Kiselev
OMEGA Company
Head of Development Departement
KiselevGA@ome.tn.corp

Dr. Aleksey Turbin
OMEGA Company
Deputy Director General
turbi60@mail.ru



RISK REDUCTION

Leak Detections Role in Reducing Pipeline Transportation Risk

> by:
> Morgan Henrie PdH > President, Expert Project Manager > MH Consulting Inc.
> Philip Carpenter > Project Manager > Serrano Services Inc.
> Paul Liddell > Project Manager > Alyeska Pipeline Service Co.

ABSTRACT

Hazardous material pipeline operators face a continuous risk associated with commodity releases. Active management of this risk is achieved through various techniques and processes such as the use of various leak detection (LD) technologies. When considering risk, the operator is faced with the trifurcation aspects of what vulnerabilities exist which could result in a spill, the likelihood that a vulnerability will be exploited and the consequences which may occur as a result of the spill. Within this trifurcation framework the paper demonstrates how LD systems contribute to the overall spill risk through consequence mitigation.

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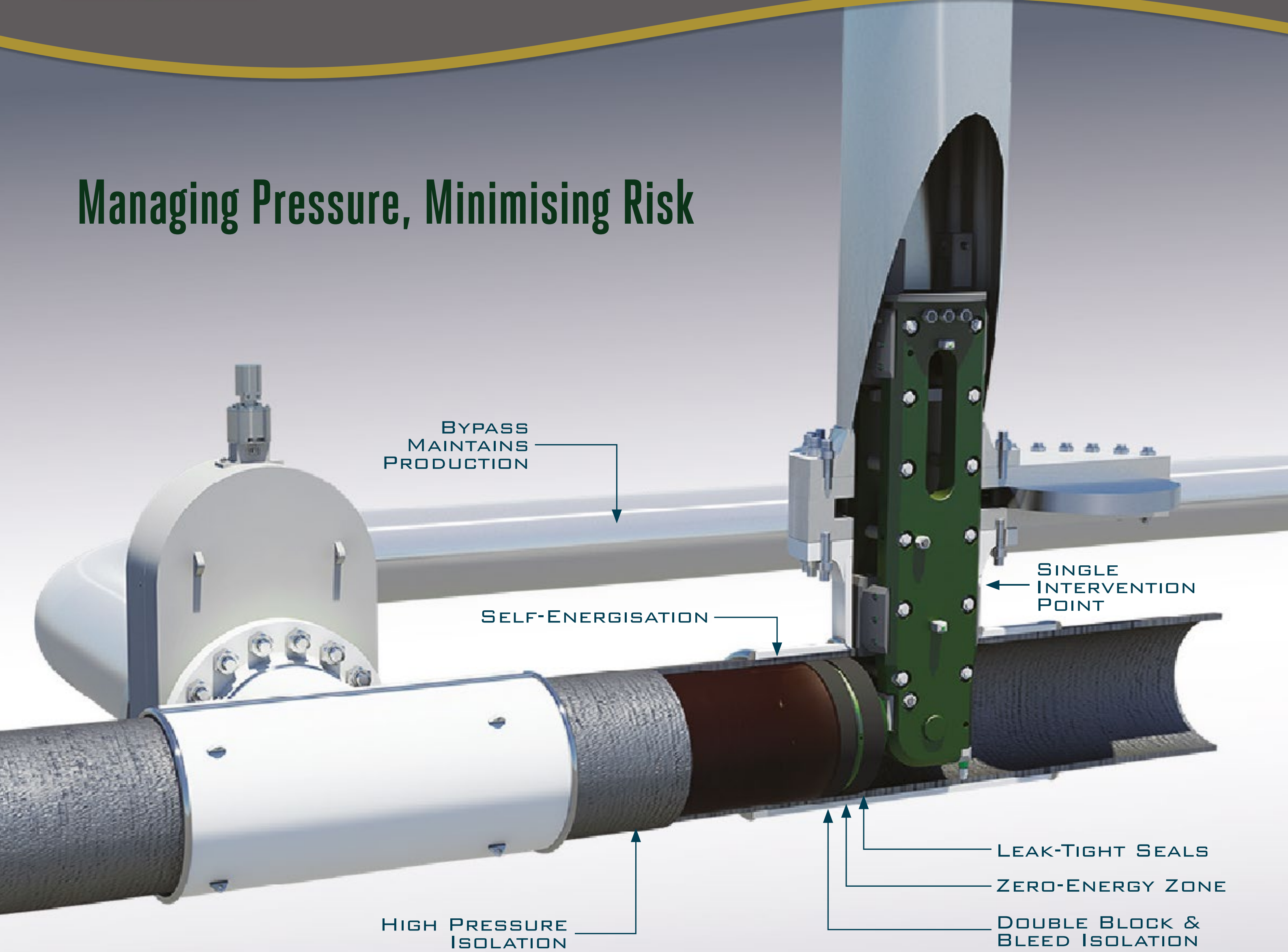

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The leak and the consequence

Potential costs due to physical injuries or damages to property and environment can easily cost millions.

Utilization of pipelines to transport hazardous liquids, such as crude oil and refined products, can be characterized as an extremely safe, efficient, and effective infrastructure. This infrastructure is extensive. As an example, within the United States (US.), the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) hazardous liquid pipeline report identifies that in 2013, the most recent information available, there were 192,388 miles of hazardous liquid or carbon dioxide pipelines, 2,149,23 miles of gas distribution pipelines, and 320,248 miles of gas transmission and gathering system pipelines.

It is also a fact that pipelines carry an inherent risk that the transported commodity will not be contained within the pipe and a spill will occur. As PHMSA notes, between 1995 and 2014, the most recently available data, the 20 year Significant incident average count, for crude oil and refined petroleum products is 251 incidents. For the same time period the total reported average barrels spilled was 72,930 which resulted in a net barrels loss of 27,953 and average property damage of $156,402,682. These are the average, annual, consequences of crude oil and refined product commodity releases or as otherwise known, spills.

Owner and operators of these pipelines apply various techniques and processes in managing the spill risk such as the use of various leak detection (LD) technologies. When considering risk, within the framework of the following equation, LD in and of itself only applies to the consequences of a spill.

Equation 1

$$\text{Risk} = \sum_{\text{All Incidents}} (\text{Probability of an Incident}) \times (\text{Consequence of Incident})$$

As Equation 1 shows risk is the resulting product of all incidents which may occur and the consequences resulting from each of these incidents. Figure 1 provides a generalized view of the linkage between vulnerability, likelihood the vulnerability is exploited, consequences and factors or influence.

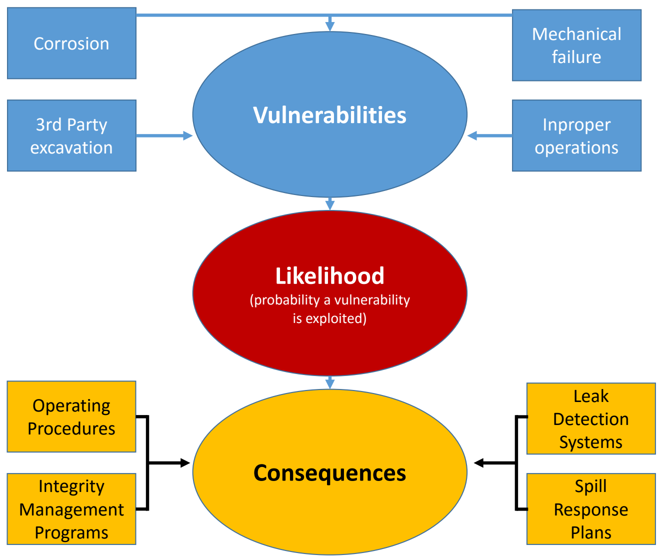

Figure 1: Generalized Risk map

Equation 2 expands on Equation 1 to identify that the probability of an incident occurring is a result of the set of pipeline threats and vulnerabilities.

Equation 2

$$\text{Probability of an incident} = \sum_{\text{All Incidents}} (\text{All threats}) \times (\text{All vulnerabilities})$$

Equations 1 and 2 illustrates how a pipeline's ultimate risk is derived from the combination of variables which include threat, vulnerability, and consequence. As the following clearly shows, leak detection systems can only assist in risk reduction by helping to mitigate the consequences of a pipeline leak and resulting spill. Leak detection systems have no impact on pipeline leak threat or vulnerabilities.

Threat, in the contexts of this article, is associated with the loss of pipeline containment which results in the release of the contained commodity. All pipelines have this common threat that a leak will occur. In general, as reported by PHMSA, pipelines have a leak incident rate of 0.58 per billion ton-miles. Thus, all pipelines have the same threat and there are no current approaches which will fully eliminate the threat as long as the pipeline is in service.

Vulnerability can be defined as a weakness in the system. As shown in Figure 2 the top pipeline weakness or vulnerabilities are failure of pipe, welds, or equipment. This is followed by corrosion and then third-party induced damage. An example is a third-party induced damage is where a construction crew is digging in close proximity to the pipe. During this work they accidently hit the pipe. The resulting strike either pipe is cracks or punctures the pipe and the commodity is released. Natural and outside forces are the next leading failure mode with incorrect operation another, but lower, contributor to pipeline incidents.

As stated, LD systems have no impact on the probability of incidents variable that result in a leak with its subsequent spill. Pipelines will have spills even if a leak detection system exists or if it doesn't exist. Historically pipelines had leaks before LD technology based systems were available and it is safe to assume that leaks will continue to occur regardless of how LD technology advancements occur. This state is a direct result that LD systems have no influence on the environments around mechanical failure, corrosion, third-party digs, and so forth. Any and all of these vulnerabilities continue to be exploited on an annual basis within the hazardous liquid pipeline industry. LD technologies do not alter the pipeline vulnerability attribute. Thus, pipeline spill incident risk, based on threat and vulnerability attributes, is not changed through the introduction of a LD system.

Because the pipeline leak threat is not eliminated and a vulnerability will be exploited leaks will occur and subsequent spill volumes will accumulate. The owner/operator risk scale is based on the consequences of that spill. Is the spill small and well contained on the minimum impact side of the consequence continuum or is it very large, in a high consequence area, with loss of life on the other end of the consequence continuum? The purpose of the LD system is to assist in reducing the spill consequence.

The point is that LD technology based systems provides the owner/operators the means to potentially identifying the occurrence of a leak sooner. The sooner the leak is identified the faster a response can be initiated. This contributes to a reduction in the resulting spill's consequence.

In summary, LD technology systems contribute to reducing the organization's spill incident risk by altering the risk equation consequence variable. As discussed, leak threat exists and will continue to exist as long as the pipeline is in operation and contains a commodity. In the risk equation threat is always greater than zero. At the same time the pipeline is subject to various vulnerabilities. The pipeline owner/operators are actively managing the various vulnerabilities but history continues to remind us that all vulnerabilities have not been eliminated. This means that the risk equation vulnerability variable is also greater than zero.

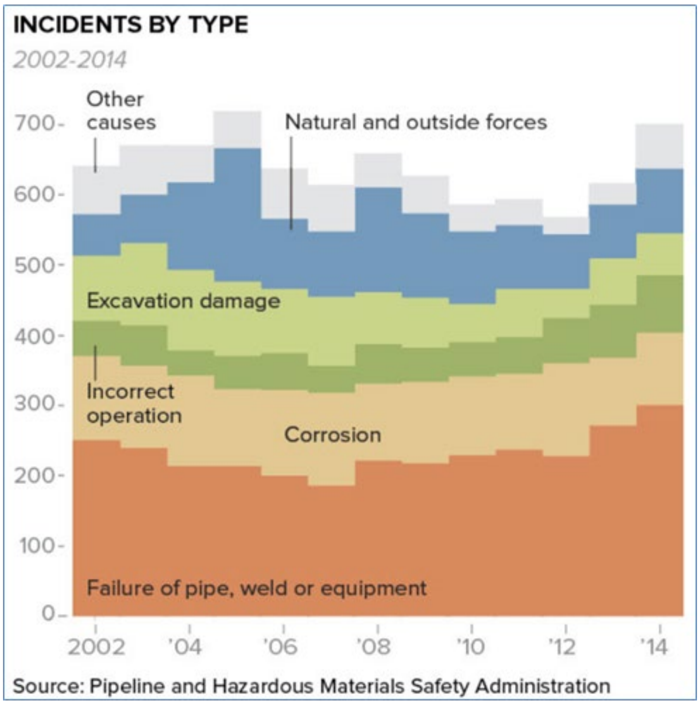

Figure 2: Incidents By Type

"Pipelines had leaks before LD technology based systems were available and it is safe to assume that leaks will continue to occur regardless of how LD technology advancements occur."

> Morgan Henrie PhD

With two out of three of the risk, or incident, equation variables greater than zero then the company leak risk level will be greater than zero unless the consequence variable can be set to zero. Unfortunately, this state does not exist as all spills have a consequence associated with them it is only the magnitude of the consequence which can be managed to a degree.

The level of consequence mitigation can be estimated by leveraging the EPA's Basic Oil Spill Cost Estimation Model (BOSCEM) in the analysis efforts. As outlined in BOSCEM, for an incident that results in a leak the resulting consequence level is dependent on the subsequent spill volume and location. Generally, a larger spill results in a greater consequence and a spill in an environmentally sensitive area, etc. will have a greater consequence as well. BOSCEM provides a method of estimating the total cost of an oil spill can be estimated using equation 3. In general, the spill volume is derived from Equation 4.

$$\text{Leak Consequence} = (C_{cleanup} \times M_{medium} + C_{soc} \times M_{location} + C_{env} \times .5 \times (M_{water} + M_{w.l.})) \times V$$

$$V = (\text{Leal Rate}) \times (\text{Detection Time} + \text{Reaction Time}) + \text{Draindown Volume}$$

Caption

$C_{cleanup}$	= per gallon response cost
M_{medium}	= medium type of spill location
C_{soc}	= socioeconomic and cultural value
$M_{location}$	= physical location where is spill occurs
C_{env}	= environmental base cost
M_{water}	= freshwater vulnerability
$M_{w.l.}$	= habitat and wildlife sensitivity
V	= volume of spill

Note 1:

The BOSCEM model is intended to quantify the relative damage and cost for different spill types for regulatory impact evaluation contingency planning, and assessing the value of spill prevention, and reduction measures.

Note 2:

$C_{cleanup}$, C_{soc}, C_{env} are (step-wise) functions of the spill volume

Note 3:

It's never the case (based on BOSCEM) that a larger oil spill is cheaper than a smaller oil spill at the same location with the same medium.

Leak Detection activities reduce the Detection Time and assists in reducing the reaction time. This ultimately reduces the spill volume. Thus, LD systems assist in reducing pipeline spill incident risks by directly impacting the consequence variable, not the threat or the vulnerability variables.

SUMMARY

leaks have historically occurred on a fairly definable frequency rate. It is safe to assume from this that leaks will continue to occur as long as the pipeline is in operation. As such, any resulting spill comes with negative consequences. To what extent these consequences expand to can be impacted through the application of appropriate LD technology systems. Appropriate LD system selection, implementation, and operation contributes to reducing the consequence variable and ultimately reducing the organization spill incident risk level.

How far the LD system alters the spill consequence variable is based on a combination of factors such as the type or types of LD systems implemented, pipeline geography, and operating conditions. As an example, if the pipeline is very simple, all above ground, within a flat geographic area, fully visible from many locations, and operated con

tinuously in a steady state then several different leak detection systems, such as visual detection, could detect a leak very quickly. In this situation the spill size should be minimal as detection time is fast and minimal drain down would occur with rapid shutdown response.

Conversely, if the pipeline system is very complex, buried, operates in a highly dynamic fashion, with minimal instrumentation this alters what type of leak detection system maybe applicable. It can also impact the ability to effectively and efficiently detect a leak which may result in larger spills occurring.

Regardless of pipeline environmental, operating, and physical characteristics, the application of and rigorous maintenance of a LD system contributes to reducing the owner/operator's leak incident risk factor through management of the consequence variable.

Authors

Morgan Henrie PhD
MH Consulting Inc.
President /
Exptert Project Manager
mhenrie@mhcinc.net

Philip Carpenter
Serrano Services Inc.
Project Manager
serrano.services@suddenlink.net

Paul Liddell
Alyeska Pipeline Service Co.
Project Manager
Paul.Liddell@
Alyeska-pipeline.com


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BRAVE NEW WORLD

MACHINE LEARNING

by:

> Maria S. Araujo	*> Manager R&D, High Reliability Systems*
> Shane Siebenaler	*> Manager R&D, Fluid Dynamics*
> Sue Baldor	*> Senior Research Engineer*
> Edmond DuPont	*> Senior Research Engineer*
> Samantha Blaisdell	*> Research Engineer*
> Daniel Davila	*> Engineer*
> Company	**> Southwest Research Institute**

Automated Small Leak Detection from Hazardous Liquid Pipelines Using Multi-Platform Remote Sensing

ABSTRACT

This paper discusses recent work focused on the development of an innovative, multi-platform, machine learning-based technology that is capable of reliably and autonomously detecting small hazardous liquid pipeline leaks in near real-time. The technology is aimed at providing reliable detection of small leaks (<1% of the nominal line throughput) without false alarms.

The technology is suitable for both mobile platforms (manned and unmanned aircraft, all-terrain vehicles, etc.) and stationary platforms, such as fixed installations at pump stations and block valve sites. The focus of the development was on the detection of liquid hydrocarbon leaks, but the technology also shows promise for detecting gas leaks.

Based on sensor input data, the system uses machine learning techniques to reliably detect "fingerprints" of small hazardous liquid leaks. The combination of the different types of sensors raises the possibility for detecting spilled product from an existing leak event, even if the leak is not actively progressing. Furthermore, the incorporation of different types and/or combination of sensors is also a possibility, making this technology very extensible.

Leak characterization was performed by imaging a variety of different types of hazardous liquid constitutions (e.g. crude oil, refined products, crude oil mixed with a variety of common refined products, etc.) in several different environmental conditions (e.g., lighting, temperature, etc.), and on various surfaces (e.g., grass, pavement, gravel, etc.).

Techniques were developed to extract a variety of features across the several spectral bands to identify unique attributes of different types of hazardous liquid constitutions in different environmental conditions, as well as non-leak events. The characterization of non-leak events is crucial in significantly reducing false alarm rates. Classifiers are then trained to autonomously detect small leaks and reject false alarms, followed by system performance testing. Trial results of this work arediscussed in this paper.

INTRODUCTION

Pipelines play a crucial role in society by delivering fuels that are needed to support pivotal needs such as transportation, heating, and power generation for businesses and general consumers. The pipeline system in the European Union is over 2,000,000 km in length with 36,000 kilometers of hazardous liquid systems [1]. These pipelines traverse a wide variety of locations, from concentrated urban centers to rural outposts, and can also go past ecologically-sensitive areas, such as waterways. The most ubiquitous means of monitoring right-of-way leaks is through computational pipeline monitoring (CPM) or Supervisory Control and Data Acquisition (SCADA) monitoring. However, there are many limitations of such systems, particularly when trying to monitor for relatively small leaks.

There have been several technologies developed in the past decade that utilize some form of remote monitoring to detect hydrocarbon leaks, primarily for gas transmission lines. These technologies require significant human resources for monitoring and interpreting information collected by remote sensors (e.g., from all-terrain vehicles, aerial platforms, and fixed installations) and are often prone to identifying liquid sources that are not leaked hydrocarbons.

Thus, there is a need for a technology that can employ machine learning to widen the application of sensor technology for many different pipeline configurations and detect leaks without false alarms. Additionally, the development of a technology that is agnostic to the delivery platform is a significant need. Desirable key features of the technology are listed in Table 1.

Feature	Details
Low false alarm rates	Less than 1% (number of events incorrectly classified as leaks) regardless of monitored area, environmental conditions, and platform. It is key for the system to be able to differentiate pooled hydrocarbon from water as pooled water should be expected during surveys.
Liquid and gas leaks	Detection of both liquid (e.g. crude, refined products) and gaseous hazardous substances (e.g. methane, ethylene).
Minimum detection size	Detection of leaks less than the most stringent reporting thresholds, typically on the order of five (5) gallons.
Autonomous detection	No need for a human to be in the loop – the system acquires, process and makes autonomous decisions on whether or not a hazardous substance was observed, using machine learning algorithms.
Near real time detection	The time between acquiring data and obtaining an output from the system is only a few minutes.
Multi-platform	Ability to deploy technology on a variety of platforms: a. Aerial: both manned and unmanned aircraft. b. Ground: both manned and unmanned systems. c. Stationary: for monitoring facilities such as refineries and pump stations.
Extensibility	Ability to nimbly integrate new detection techniques into systems for other types of target substances.

Table 1: Key Features of Effective Leak Detection Technologies

TECHNICAL APPROACH / OVERVIEW

The research presented in this paper uses machine learning techniques to autonomously detect "fingerprints" of small hazardous liquid leaks. The sensors used were optical sensing-based technologies, largely due to the fact that these technologies have shown great efficacy in detecting leaks, and are typically nonintrusive in nature. Additionally, while much of the work in applying optical sensing technologies to pipeline monitoring has concentrated in evaluating and improving this efficacy, limited work has been accomplished in developing autonomous (i.e. no human in the loop), real-time techniques for detecting leaks. This is where the machine learning techniques play a significant role.

The first stage of the research involved the use of multiple optical sensors, including long-wave infrared (LWIR), short-wave infrared (SWIR), hyperspectral, and visible cameras. The use of multiple cameras at the early research stage was focused on identifying the bands of the spectrum in which unique hazardous liquid features can be found. The next step was to then eliminate the cameras for which little or no relevant information is obtained, with the ultimate goal of having as little cameras (sensors) as possible. Leak characterization was performed by imaging a variety of different types of hazardous liquid constitutions (e.g. crude oil, refined products, crude oil mixed with a variety of common refined products, ethylene, methane, etc.) in several different environmental conditions (e.g., lighting, temperature, etc.) and on various surfaces (e.g., grass, pavement, gravel, dirt, etc.).

The technology employs a multi-stage processing pipeline to achieve accurate detections. This allows for multiple opportunities to increase the accuracy of detection while lowering the occurrence rate of false positives. Figure 1 shows the main stages of this pipeline.

"The core of the technology is the use of machine learning techniques, which enable reliable material classification as well autonomous operations."

> Maria S. Araujo.

Multiple images feed into the first block, Sensor Registration, where a transformation on the image data ensures the field of view in each camera is the same. Next, in Feature Extraction, multiple features, including texture-characterizing features, are calculated for each image. The feature vectors are passed into a Classifier that makes a decision if and where in the image a particular hazardous liquid is, and scores the confidence in that decision. Lastly, Post-Processing cleans up lowconfidence decisions and sources of noise.

While the work involved the use of optical sensors, it is important to note that the core of the technology is the use of machine learning techniques, which enable reliable material classification as well autonomous (no human in the loop) operations. These machine learning techniques are sensor-agnostic, as can be seen in Figure 1. As such, the incorporation of different types and/or combination of sensors (including non-optical sensors) is also a possibility, making the technology very extensible.

IMPLEMENTATION

The technology development focused on the detection of hydrocarbon liquids perceivable above the ground surface. In this case, passive optical sensors were used to capture the environment and train a classification system to automatically detect the presence of hazardous liquids. Machine learning techniques were then developed to evaluate how electromagnetic energy interacts with hazardous liquids across a broad range of the electromagnetic spectrum.

The data collection encompassed a variety of substances, including mineral oil, crude oil, diesel, gasoline, and water as standalone liquids and over surfaces that included concrete, grass, dirt, and gravel. The tests also included water, a common source of false positives, and thus a key component in developing a robust approach. Spectral range and resolution for each of the cameras used is summarized in Table 2. These cameras simultaneously captured frames containing the hazardous liquids in a representative environment.

Camera	Spectral Range	Resolution
SOC710VP HS-Portable Visible/NIR	0.4µm - 1µm	696x520
Sensor Unlimited 640CSX	0.9µm - 1.7µm	640x512
FLIR A65	7.5µm - 13µm	640x512
UI-5240SE	0.4µm - 0.9µm	640x480

Table 2: Optical Sensors Used In Development of Leak Detection Algorithms

An image registration approach was applied to map the images between all the cameras. This allows for the analysis of the sensor systems independently and collectively. The registration is performed prior to applying the machine learning algorithms to detect the presence of a hazardous liquid.

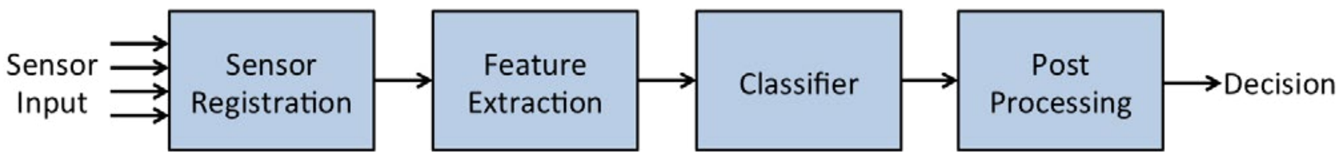

Figure 1: Leak Detection Processing Pipeline

It is important to emphasize that the cameras themselves are not the key factor of the technology; in fact, for a deployable optical-based solution, the cameras would need to be different, as different resolutions would be needed. The pivotal aspect of the technology is its ability to, based on sensor input data and classification parameters, autonomously predict in real-time what the sensed input is.

A setup was devised in which various combinations of fluids and visible surfaces were placed in low-profile containers, as shown in Figure 3. This controlled setup was used to capture the spectral response of the different liquids with the different cameras for offline evaluation. To simulate the expected ground surfaces that are commonly found near pipelines, the data collection included adding concrete, grass, dirt, or gravel to each liquid under test to capture any changes in their spectral response. The hazardous liquids remained on the surface in some cases and were absorbed by the solid compounds in other cases.

The spectral response changed based on the temperature of the liquid, the duration the liquid is on the surface, and the environmental conditions during the course of the leak. During the data collection, the liquids were not heated or cooled by any external source, but only from the environment at the time of collection. For each test, data was collected in a manner such that temperature variations, absorptions, and evaporations due to the environment and the underlying surface conditions were captured. Data collection was also performed during various times including dusk, midday, evenings, direct sunlight, and shade to capture various lighting conditions and ambient temperatures. Similar tests were conducted for gaseous substances, in which controlled gas releases were simulated, as shown in Figure 2.

The collected data was analyzed to determine unique signatures and distinguishable features that can be defined to classify the existence of hazardous liquids. The analysis applied feature extraction and classification methods that leveraged the following:

- Spectral Information: The spectral information contains reflectivity data for a large number of discrete bands across specific ranges of the electromagnetic spectrum.

- Spatial Information: The spatial information describes the real world representation of the liquids, such as scale and texture.

Each of the liquids presented different luminance and texture characteristics, based on their relative electromagnetic response captured by the cameras. The characteristics were manually selected in each of the cameras, in order to define ground truth labels to train the classification system. A set of feature extracting methods were developed and applied to identify related geometric formations (e.g. area, boundary), texture, and context information in the image. These features were applied to the spectral and spatial information, both collectively and independently, to transform the ground truth labels into discriminant components to use as inputs to train a classification system. The combination of features which best discriminates the hazardous liquids from non-hazardous substances is of high importance for the classifier and for the method's robustness, as it directly drives not only leak detection rates, but also false positive rates.

Figure 2:
Hazardous liquids on dirt (small picture) and gas (liquid nitrogen) release test (big picture)

The classification system is applied to distinguish hazardous liquids from the water and other non-hazardous materials in the environment. The classifier learns patterns from the extracted ground truth labeled features (training step) and, at a later stage on an unknown set of feature-extracted samples. Classifiers are then called to make a decision (classification step) on the existence of hazardous material. The classification output was defined on a pixel basis, followed by post-processing techniques to remove falsely detected pixels and group true positive regions, in order to better define the hazardous liquid formation within the image.

TRAINING AND EVALUATION

The data used for initial validation purposes was collected under a variety of weather conditions, and at different times of the day, in order to obtain a wide range of lighting conditions. The set consists of images taken at a distance of approximately ten (10) meters (between sensors and target substance) using hyperspectral, visible, thermal, and short-wave infrared (SWIR) cameras. Figure 3 shows a typical setup for simulating situations of interest both from the visible camera and the thermal camera perspectives. The black bins in the foreground each contain a combination of:

1. a typical ground surface found underneath a pipeline, and
2. a liquid coating which is either a hazardous liquid or a potential false positive, such as water.

Table 3 lists some of the surfaces, liquids, and lighting conditions used for data collection.

Surfaces	Substances
Gravel	Mineral Oil
Grass	Gasoline
Dirt	Diesel
Concrete	Crude Oil
	Water
	No liquid (surface only)
	Methane
	Ethylene

Table 3: Subset of Surfaces, Liquids and Lighting Conditions Used During Data Collection

Additional test data was collected of potential sources of false positives. These included images during varying lighting and weather conditions. Test images included natural landscapes such as trees, grass, and leaf beds. Potential objects of interest in the additional test image sets include vehicles, metal structures, pipes, and people.

From the set of images collected, samples were extracted to populate classes for testing and training. A class is defined to be a combination of liquid type and surface. To ensure independence between samples, separate sets of images were used for training and testing the classifier. Additionally, as the images were collected from a video stream running at 30 frames-per-second, the sampling of chronological images was spaced strategically, in order to capture the largest possible range of independent samples throughout the tests. The regions of interest defined over the images were sampled randomly to generate class data.

In order to evaluate classifier performance, several scoring metrics were used including accuracy, precision, recall, F1 score (measure of a test's accuracy), hazardous liquid false alarm rate, and hazardous liquid missed detection rate. In this context, the false alarm rate is defined to be the percentage of non-hazardous liquid pixels (water, surface only, other), incorrectly classified as hazardous liquid pixels (mineral oil, gasoline, diesel, crude oil). Similarly, the missed detection rate is defined to be the percentage of hazardous liquid pixels (mineral oil, gasoline, diesel, and crude oil), incorrectly classified as non-hazardous pixels (water, surface only, other). The goal of this classification effort is to maximize accuracy, precision, F1 score, and recall, while minimizing hazardous liquid missed detections and false positives. These metrics are observed on the full set of test data to encompass many possible relevant leak and non-leak conditions.

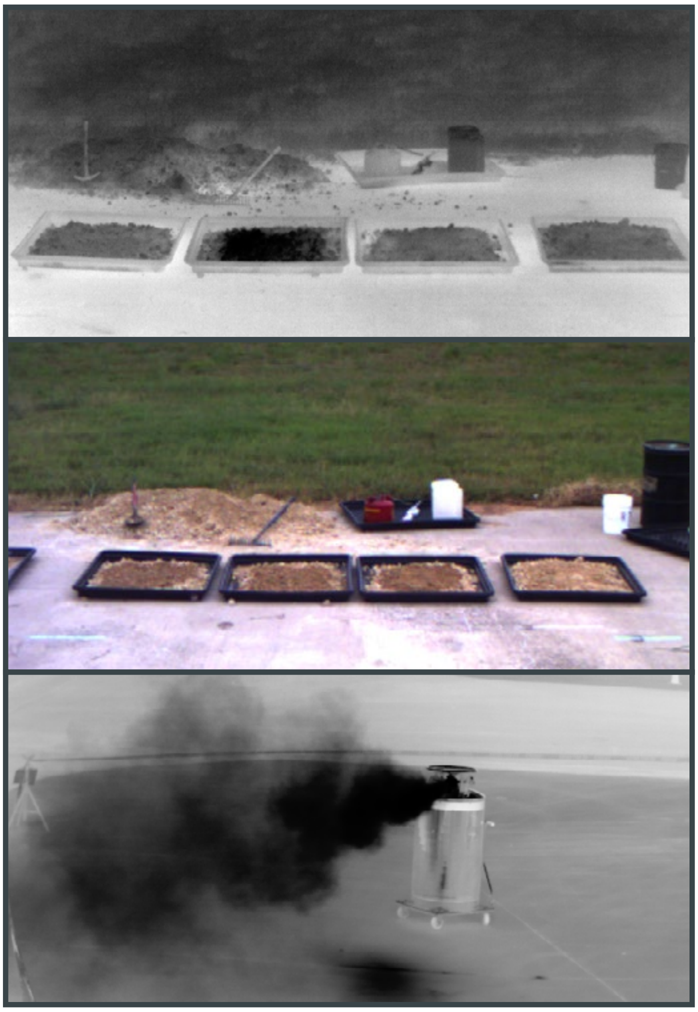

Figure 3: Various Liquids on Gravel Surface (Visible Camera Left, Thermal Camera Middle), Nitrogen (Bottom, Thermal Camera)

RESULTS

The classification results for various test conditions are illustrated in Figure 4 a-d and tabulated in Table 4. These result images show in red the detections of hazardous liquids (mineral oil, gasoline, diesel, and crude). In Figure 4-a and Figure 4-b, the plastic bins in the foreground contain, from left to right, a surface with mineral oil, gasoline, diesel, and water. In Figure 4-c, the bins each contain a different surface with crude oil on top. Figure 4-d contains a test image in which no hazardous liquids are present. These detections are the result of combining the output of both the visible and thermal cameras.

It is expected that these false alarm rates will go down even further (very close to zero) as more data is collected, more diverse scenery is included in training, the feature selection process is refined, and post-processing is performed. Postprocessing may include configuring thresholds to govern the minimum number of pixels in a region along with the classifier certainties necessary to be reported as a true positive. Testing has also shown that relevant features could be extracted from the SWIR and hyperspectral cameras, the former of which is particularly well-suited for characterizing vegetation. This could be especially beneficial to the classification process in further reducing false positives.

Figure 4: Hazardous Liquid Detections for Various Test Cases (Red)
Areas in red reflect locations in which the algorithm autonomously detected the presence of a hazardous liquid (crude oil and/or refined products)

A: Hazardous liquid on sod surface

C: Crude on multiple surfaces

B: Hazardous liquid on gravel surface

D: Wet surfaces, no hazardous liquid

Metrics	Hazards on sod	Hazards on gravel	Hazards on dirt	Hazards on concrete
Accuracy	0.996675	0.952678	0.999899	0.99964
Precision	0.995941	0.932763	0.999922	0.999494
Recall	0.998214	0.932653	0.999895	0.999645
F1	0.997060	0.932707	0.999908	0.999493
False alarm rate	0.000042	0.038962	0.000063	0.000402
Missed detection rate	0.0	0.058900	0.0	0.0

Table 4: Subset of Surfaces, Liquids and Lighting Conditions Used During Data Collection

FUTURE WORK

In the near future, algorithm development and refinements will be conducted to lower the false alarm rates even further, as previously discussed. A variety of tests will also be conducted in order to assess system performance and quantify the following parameters in detail:

- Leak Detection Rate: For a variety of test scenarios, percentage of simulated leaks that are detected by the system.
- False Alarm Rate: For a variety of test scenarios, percentage of false alarms that are triggered by the system.
- Real-Time Performance: For each leak detection event, time elapsed from first "sighting" of leak until leak alarm is triggered by system.

Because the processing pipeline described in Figure 1 adapts easily to a variety of sensors, different types of sensors could be used for data collection, such as LIDAR, ultrasonic, chemical and others. For non-imaging sensors, features could be extracted from the data and used for classification.

Lastly, the algorithms developed will be ported to a prototype embedded platform that is suitable for deployment on an aerial or ground platform (e.g. manned aircraft, UAV, ground vehicle). That prototype system will then be used for validation/performance testing of this new liquid leak detection technology in an operational scenario. More specifically, validation of the technology will be conducted:

1. On an aerial platform inspecting a real or representative pipeline (with simulated leaks).
2. On a stationary platform, monitoring simulated leaks at a facility (e.g. compressor and pump station).

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CONCLUSION

The predominant leak detection systems used today to monitor hazardous liquid pipelines are not designed to detect leaks below 1% of nominal flow rates. False alarms of any leak detection system are a major industry concern, as they lead to alarms being ignored, resulting in leak detection systems that are ultimately ineffective. The technology presented in this paper addresses key gaps that exist today in prevailing leak detection systems, including:

- Near real-time, autonomous leak detection and reporting; no need for a human to be in the loop.
- Repeatability and confidence in detection (low false call rate).
- Multi-platform (aerial, ground, manned and unmanned).
- Detection of small leaks (less than 1% of pipeline throughput).
- Ability to nimbly integrate new detection techniques into the system for other types of target substances.
- Ability to integrate leak detection alarms into existing pipeline communication infrastructures (e.g. fiber optic cables), in order to provide geo-referenced alarms in near real-time to remote monitoring facilities.

While the work presented in this paper involves the use optical sensors, the core aspect of the technology is the use of machine learning techniques, which enable reliable material classification as well autonomous (no human in the loop) operations. These machine learning techniques are sensor-agnostic, which allows for the incorporation of different types and/or combination of sensors (including non-optical sensors), making this technology very extensible.

Authors

Maria S. Araujo
Sue Baldor
Shane Siebenaler
Edmond DuPont
Samantha Blaisdell
Daniel Davila
Southwest Research Institute San Antonio, USA
Contact: maria.araujo@swri.org

CHARM® 2

First experiences with the application of the next CHARM® generation

> by: Dr. Axel Scherello > Project Leader CHARM® > Open Grid Europe GmbH

Abstract

In order to improve the efficiency of leak detection surveys for high pressure natural gas pipeline grids airborne laser based detection methods have been developed during the last years. Diverse requirements for different countries and their individual gas guidelines were the basis for the enormous variety of airborne gas remote detection systems. CHARM® is by far the most sophisticated system. Nevertheless due to the voluminous equipment a larger helicopter model with higher operation costs have to be used.

In order to decrease the relative operation costs per kilometer of proven pipeline a new generation of CHARM® was developed over the past years. A ten times faster laser is in operation in the so called CHARM-2 system which allows a faster processing with wider inspection corridors.

This contribution to the Pipeline Technology Conference 2016 will describe the advantages of the new system compared with the first generation of CHARM® and other gas remote detection systems. First practical experiences regarding the application of CHARM-2 surveying Open Grid Europe's own pipelines will be presented.

INTRODUCTION

Natural gas pipeline inspections are mainly carried out on the ground by walking surveys using mobile gas detectors to check for leakages. This method is very time-consuming and labor-intensive. The CHARM® remote gas detection system (CH4 Airborne Remote Monitoring) developed and supplied by Open Grid Europe is the state-of-the-art inspection system for natural gas transport pipelines. CHARM® can be used for inspecting pipelines under a soil cover or under sealed surfaces.

BASIC GAS REMOTE DETECTION

The method is based on an infrared laser system installed on board a helicopter and is capable of precisely detecting even very low methane concentrations. Open Grid Europe offers this highly efficient and flexible way of natural gas pipeline tightness checking to gas transport companies all over Europe. Accurate methane level measurements require the use of satellite navigation systems to determine the precise location of the helicopter in combination with geographic information systems containing details of the pipeline route. Any questionable pipeline section identified by CHARM® can be fully examined and evaluated on site by technical teams. This approach makes it easier and less costly for gas suppliers to comply with their inspection obligations and to maintain high safety standards for their gas supply infrastructure.

Natural gas detection systems used for monitoring the tightness of buried pipelines must be capable of identifying even the smallest traces of methane. The CHARM® technology is based on the differential Absorption LIDAR (DIAL) measurement principle, an established active remote sensing method for detecting different gases in the atmosphere. The LIDAR (Light Detection And Ranging) technique involves transmitting laser light and detecting and analyzing the light back-scattered by the atmosphere or a solid target object like the ground. Trace gas concentrations can be determined by tuning the laser wavelength to the spectral signature and absorption characteristics of the gas to be measured.

"The CHARM® technology is capable of identifying even smallest traces of methane."

> Dr. Axel Scherello

CHARM® in action: a test flight in Germany

The measurement principle CHARM® is based on a special kind of LIDAR technology. A high frequency laser inside the helicopter sends out laser light pulses at the pipeline. When it hits the ground the light is scattered in all directions. The small fraction of the emitted light that is scattered back to the system on board of the helicopter is focused and fed to a detector for analysis.

In order to eliminate the atmospheric influences and ground surface backscatter effects on the measurement signal, the DIAL technique uses light pulses of two different wavelengths. Pulses of the measurement wavelength (λon) are absorbed by methane while pulses of the second wavelength (λoff) are not absorbed and serve as a reference. Differences in backscattered signals are converted to integrated concentration-length-values.

CHARM® includes a specially developed software package allowing inspection flights to be scheduled and analyzed within a short space of time. All coordinates, measuring points and events are accurately recorded, with photographs taken for additional documentation.

DETECTION OF VERY LOW METHANE CONCENTRATIONS

CHARM® is securely installed on a helicopter and protected from vibrations. Control systems ensuring spatial stabilization of the laser beam compensate for the effects of movement and direct the measurement beam precisely towards the pipeline's centerline. Differential GPS (Global Positioning System) allows highly accurate localization of the helicopter. The system is combined with an inertial measurement system (IMS) for accurate helicopter positioning in order to target the measurement beam automatically and precisely onto the pipeline corridor (CHARM®-Auto-Tracking, CAT). When operating at an altitude of around 120 m, the CHARM® system generates laser spots of about 1 m diameter on the ground. Using a scanner, the laser spots cover a corridor along the pipeline route which can be as wide as 30 m.

When gas escapes from a buried natural gas pipeline, it is dispersed in layers near to ground level. It is not possible to predict the dispersal path, so in some cases the gas may not emerge directly above the leak but several meters away from the pipeline. CHARM® scans a corridor with a width of up to 30 m along the pipeline route. The generous width of the corridor significantly increases the probability of detecting any leaks. The system's highly automated mode of operation and regular in-flight checks ensure that all components are fully functional and available for use. All flights are automatically and extensively documented to provide evidence that the required pipeline inspections were carried out appropriately.

Compared to the first generation of CHARM® the second generation is equipped with a faster laser, emitting 1,000 laser double pulses instead of 100. This ten times faster signal productions enables the helicopter to speed up its cruising speed. Unnecessary return flights can be avoided due to much denser track coverage with laser spots. Pipeline sections with complex topology or looped pipelines can be simply checked with only one flight. Overall the net capacity increase for CHARM-2 should be doubled compared with its first generation. Due to the early editorial deadline no details regarding practical numbers were available. Results will be given at the conference.

CHARM® CERTIFIED BY DVGW

DVGW, the German technical and scientific Association for Gas and Water, has published a technical rule (guideline G 501) for airborne remote gas detection defining the functional and procedural requirements for these methods. CHARM® is the only system to meet these requirements and has been certified by DVGW. It has been shown to be capable of checking buried pipelines in built-up areas as well as in open country for tightness and detecting even the smallest leakages with gas flows as low as 100 l/h. In cooperation with energy companies and gas network operators, a comprehensive program of tests to determine the system's fitness for purpose was conducted under the responsibility of the DVGW research unit at the Engler-Bunte-Institute of Karlsruhe Technical University. As part of these tests, different parameters such as the quantity of the released gas, the climatic conditions as well as the altitude and speed of the helicopter were repeatedly modified. The tests confirmed that CHARM® is capable of reliably inspecting high-pressure pipelines to a high standard in accordance with the applicable codes of practice.

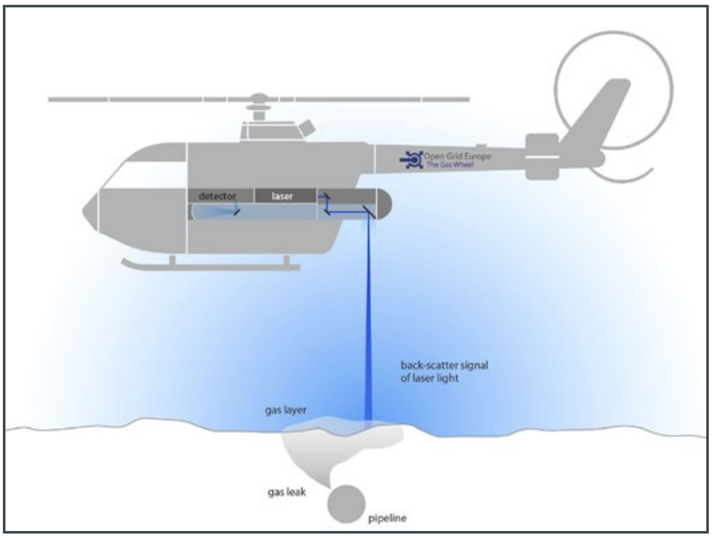

Figure 1: LIDAR principle

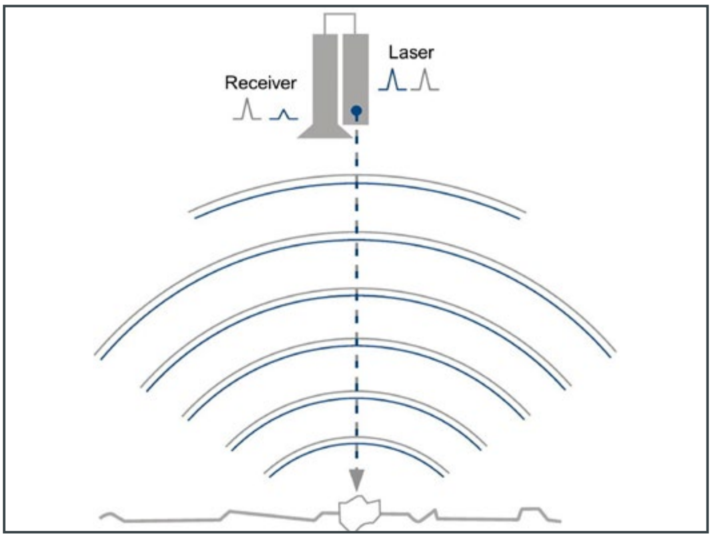

Figure 2: Differential Absorption LIDAR

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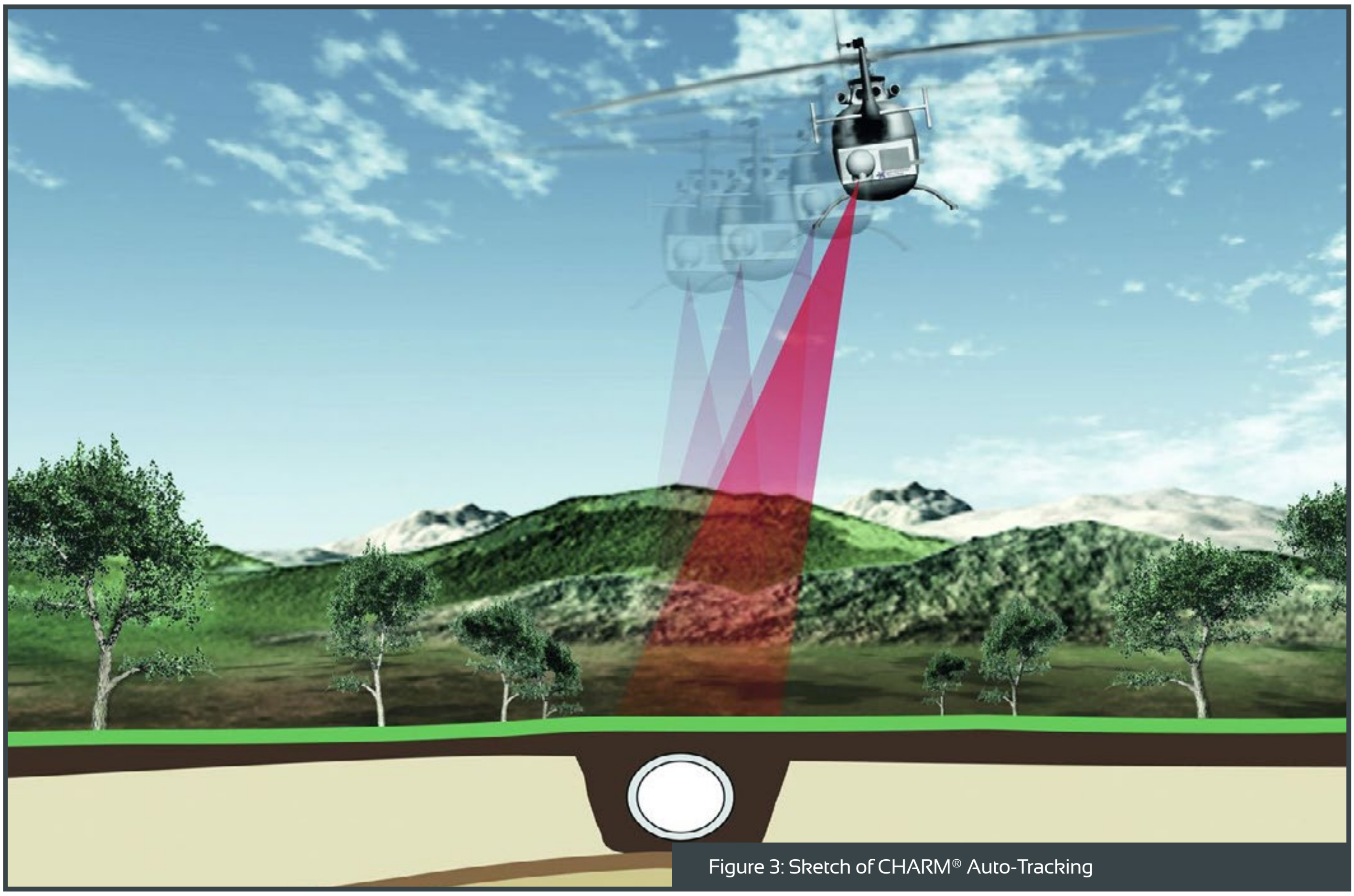


Figure 3: Sketch of CHARM® Auto-Tracking

CHARM® AT A GLANCE

- Airborne infrared laser-based remote gas detection system
- Even smallest traces of natural gas are safely identified from altitudes of 80 to 140 m
- High methane sensitivity allowing detection at levels of 5 ppm · m and over during operation
- Full coverage of pipeline routes over widths of up to 30 m
- Accurate geographic positioning of measurement beam with CHARM®-Auto-Tracking (CAT)
- High detection frequency, 1,000 double pulse measurements per second
- High patrol speed during inspection (50–150 km/h)
- Automatic function checks ensure that all system components are working properly
- Automated documentation of pipeline inspection and real-time reporting of indications
- High-tech method to supplement conventional pipeline inspection procedures
- Certified to DVGW Guideline G 501: "Airborne Remote Gas Detection Methods"
- Photographic documentation of inspection flights provides knowledge of the general condition of the pipeline route
- Practical verification: Detection of an underground leakage of 150 l/h under practical conditions and with wind speeds > 3 m/s

DEVELOPMENT PARTNERS

Apart from Open Grid Europe, the following organizations were involved in the development of CHARM®:

Adlares GmbH, Air Lloyd Deutsche Helicopter Flugservice GmbH, Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), PLEdoc Gesellschaft für Dokumentationserstellung und -pflege mbH

Author

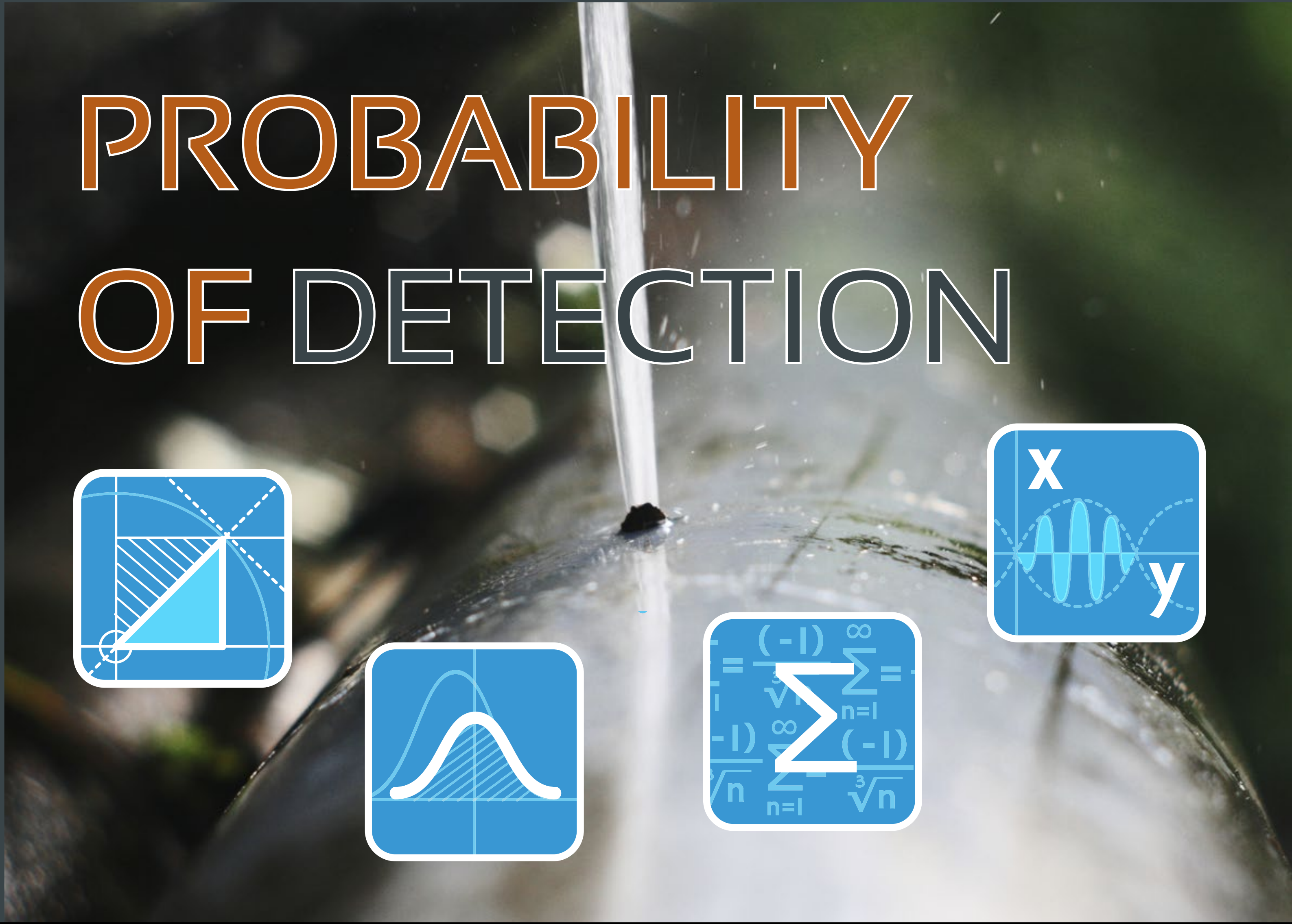
Dr. Axel Scherello

Open Grid Europe GmbH

Project Leader CHARM®

axel.scherello@
open-grid-europe.com

PROBABILITY OF DETECTION



History, Development and Future

> by: Arvind Keprate > Research Fellow > University of Stavanger, Norway, Department of Mechanical & Structural Engineering and Materials Science

ABSTRACT

It is a common practice in the oil and gas industry to employ various Non-Destructive Evaluation (NDE) methods during in-service inspections to detect the cracks in the pipeline. The capability of NDE method is expressed by the metric called as the Probability of Detection (POD), which is stated as a function of crack size through the POD curve. This manuscript thus deals with various aspects of POD. Firstly, a brief discussion about NDE reliability and POD is presented. Thereafter, based on the literature review the history and development of POD curves is provided. Finally, a brief discussion about the future of POD i.e. model assisted POD is presented.

ACADEMIC RESEARCH

INTRODUCTION

Several Non-Destructive Evaluation (NDE) methods are used in the offshore industry for the detection of the flaw in the welded structures [1]. A brief discussion about the aforementioned is presented in the American Society of Metals (ASM) Handbook [2]. The NDE industry classifies the NDE methods as conventional and advanced. While the conventional NDE include methods such as radiography testing (RT), ultrasonic testing (UT), dye penetrant, visual inspection, Eddy Current (EC), etc., the advanced NDE techniques are Acoustic Emission (AE), Thermal Infrared, Phased array, Time of Flight Diffraction (TOFD) etc. [3].

While performing a NDE activity, besides the NDE cost, expenses are also incurred for the associated scaffolding, lagging removal, and cleaning/preparation activities that go with them [3]. Thus, selection of a particular NDE technique for an in-service inspection must be performed carefully [3]. Generally, it is necessary to understand the problem under consideration before selecting a particular NDE method. For e.g. if in-service inspection requires the volumetric examination of the welded structures, then UT and RT are preferred NDE methods over other conventional NDE techniques [2].

Even though several advanced NDE methods are available for use, still 90% of the NDE techniques used during the in-service inspection are conventional as depicted by Fig. 1 [3]. Since the conventional NDE methods takes the lion's share in the in-service inspection domain, so it is vital to compare the aforementioned on various attributes as shown in Table 1 [4]. The effectiveness of the NDE method is quantified by the term NDE reliability, which is defined as "the probability of detecting a crack in a given size group under the inspection conditions and procedures specified" [5]. NDE reliability is expressed in terms of the flaw size having a detection probability of 90%. The aforesaid crack size is known as a90 crack size [6]. Nevertheless, there is certain statistical uncertainty associated with the value of a90, which is represented by stating, a 95% confidence interval. This crack size is represented as a90/95 and serves as an important parameter to quantify NDE reliability [6].

The three facets of the NDE reliability are reproducibility, repeatability and capability. The metric used to measure the NDE capability is known as Probability of Detection (POD) and is defined as "the probability that a given damage in a component will be detected using a given inspection method" [7]. Other definitions of POD are available in the literature; nevertheless, all of them indicate a strong correlation with flaw size, which is represented as POD curve as illustrated in Fig. 2 [1]. It is important to have an understanding of the way POD curves are derived. Hence, this manuscript, presents the history and development of the POD curves in Section 2. Thereafter, in Section 3 a brief discussion about the future of POD i.e. model assisted POD is outlined. Finally, the conclusion is presented in Section 4.

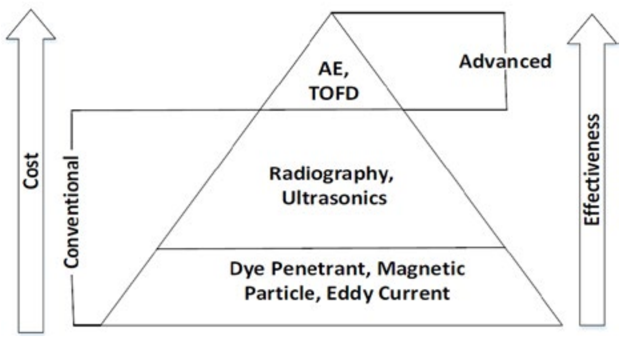


Figure 1: Usage of NDE Methods During In-Service Inspection [3]

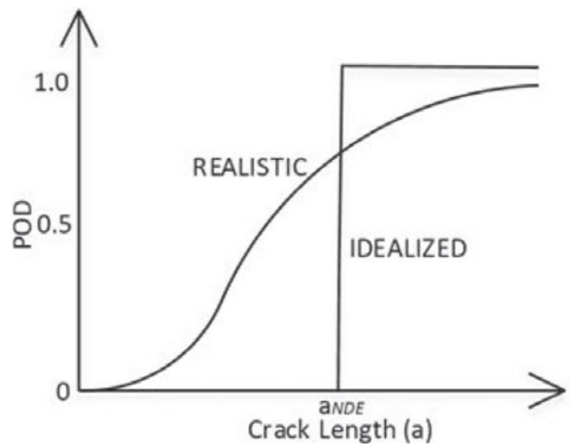


Figure 2: Realistic Vs. Idealized POD Curves [5]

HISTORICAL BACKGROUND AND DEVELOPMENT OF POD

ORIGIN OF THE POD

The use of the POD functions as a metric for quantifying the NDE capability have undergone considerable development circa late 1960's and early 1970's [8]. In 1969, the National Astronautics and Space Administration (NASA) recognized the need for NDE quantification for design and production of the space shuttle [9, 10]. In order to meet the damage tolerance requirement, NASA appraised NDE reliability based on the largest flaw, which is possible to be missed rather than the smallest flaw that is possible to be detected [9,10]. The need for this transition was felt because detecting the smallest flaw by NDE method was more cumbersome and less reliable, than detecting the largest flaw that could be missed by a NDE method. Fig.3 depicts the hit/miss data and illustrates a gap between smallest flaw detected and largest flaw missed.

The NASA methodology of quantifying NDE capability was incorporated in the standard NASA-5009 and was soon adopted by the US Air Force (USAF) by issuing the document MIL A-83444 [9, 10]. Thereafter, the concept of the POD was introduced in 1973 and was incorporated into the design requirements for the NASA Space Shuttle program [11]. The NASA POD development project was pioneering work in quantifying the NDE capabilities and was soon accepted as a standard method.

The initial plots of POD curves were constructed using moving averages, and manually fitting a curve through these points [12]. Thereafter, large number of methods were formulated to draw the POD curves. The equation POD (a)= $\frac{n_d}{n}$ served as the main equation of these methods and binomial statistics was used to calculate the confidence bounds [13]. Nevertheless, this non-parametric method was inadequate as it produced coherent results for a single flaw size, but often led to the requirement of extremely large sample sizes to obtain reasonable lower confidence bounds on the POD [14].

Thereafter, in 1978 a final report [15] of a large NDE reliability program carried out by the USAF and statisticians based on the logistic regression to analyze hit/miss data was issued [16]. The program was called "Have-Cracks-Will-Travel" and the experimental data from the program included numerous examples of two cracks of approximately equal length having significantly different POD. These results clearly demonstrated that besides crack length, the POD was influenced by many other factors [17].

It is to be noted that the "Have-Cracks-Will-Travel" data was recorded in terms of 'hit/miss' only. Based on the analysis of the above data, Berens and Hovey [16] proposed a probabilistic description of POD, "as a curve through the averages of detection probabilities for all cracks of the same length". They called such a curve as regression curve. The aforementioned approach was documented in an American Society for Testing of Materials (ASTM) Special Technical Publication [17]. It is mentioned in the aforementioned document that log-odds models of the POD provides better estimates of the POD with less scatter, as compared to the non-parametric method which used binomial based estimates.

"The NASA POD development project was pioneering work in quantifying the NDE capabilities and was accepted as a standard method."

> Arvind Keprate

NDE Method	Sensitivity (Crack Length in mm)		Adaptability to Field Use				Instrumentation of Method		
	In Welds	In Joints	Vibration	Temperature	Access	Surface Preparation	Complexity	Automation	Operator Dependence
Ultrasonic Testing	3-7	7-13	Good	Good	Fair	Moderate	Moderate	Fair	High
Radiography Testing	13-25	13-25	Fair	Good	Poor	Low	Moderate	Poor	High
Eddy Current	7-13	>25	Good	Good	Excellent	Low	Moderate	Good	Moderate
Magnetic Particle Inspection	3-7	>25	Good	Good	Fair	Moderate	Low	Poor	High
Dye Penetrant	7-13	>25	Good	Fair	Fair	High	Low	Poor	High

Table 1: Comparison of the Conventional NDE Methods [4].

EXTENSION OF THE POD ANALYSIS

The next evolution of POD was driven by development of the automated EC which besides 'hit/miss' data, allowed the collection of signal response, which may be interpreted as the perceived flaw size (i.e. â vs a" data). A method of estimating the POD function from â vs a" data was presented in [18]. The review of the signal response data indicated that the data was generally linear on a logarithmic scale and the variance was normally distributed around the mean, independent of crack size [19]. Thereafter, Berens showed that 'log-normal' or 'Probit' was the best fit for the signal response NDE data [11].

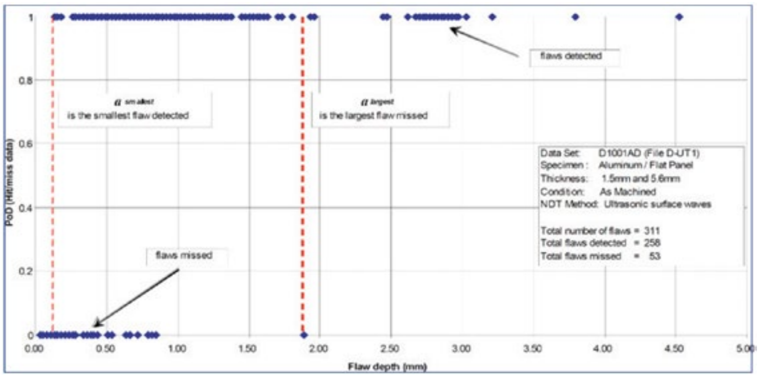


Figure 3: Ultrasonic NDE Hit/Miss Data Depicting Gap between Smallest Flaw Detected vs. Largest Flaw Missed [11].

Until late 90s the work done by Berens, as published in the ASM Handbook was treated as the main reference standard in the field of POD evaluation [14]. Later, this work was documented into the US Department of Defense (DOD) Handbook for POD studies, which was published in 1999 [20]. The main challenge in the development of POD was to calculate the confidence interval (CI) accurately [21]. Since 2000, several modifications have been suggested for POD CI calculations [20]. Firstly, the CI for 'hit/miss' data were considered overly conservative as they were applied simultaneously to all the points on the POD curve. This method of calculating CI was based on the so called Wald Statistic [21]. Later, the likelihood ratio method was recommended as a more accurate method for CI calculations [22].

MIL-HDBK-1823 was revised to include these developments in POD CI calculations and finally MIL-HDBK-1823A (an updated version of MIL-HDBK-1823) was published in 2009 [23]. At present, MIL-HDBK-1823A is considered as the state-of-the-art guidance for conducting POD studies by the USAF and other industries.

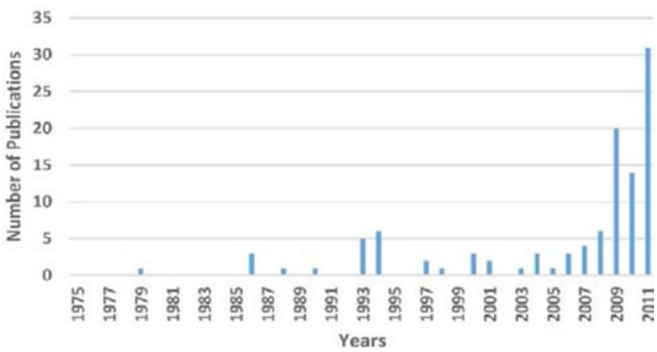


Figure 4: Number of Publications on POD in the Field of NDE [35].

TRANSITION TOWARDS THE COMPUTATIONAL POD

Until mid 90s the reliability of NDE inspection had traditionally been evaluated by experimental trials. Since it was a laborious and time consuming task, this led to transition in the POD curve generation philosophy from experimental to computational models, most notably within UK National NDT Centre and also in the USA [24].

In 1989, Gray and colleagues at Iowa State University published a paper reviewing NDE reliability models. The authors concluded that due to the time and economic reasons there is a need to come up with the computational models for predicting the NDE reliability [25]. Later in 1990, Nakagawa, at Iowa State, and Beissner, at Southwest Research Institute, used a novice approach of substituting the experimental flaw signals with the theoretical physical modeling technique [26]. The authors concluded from their work, that computer simulations are possible replacement of a large number of experimental EC measurements to determine POD for the fatigue cracks [26].

Contemporary to the efforts on modeling of POD at Iowa State University, researchers at Harwell Laboratory in Oxford were also pursuing development of computational POD models. Ogilvy in 1993 created a mathematical model to predict the theoretical POD of planar buried defects from conventional ultrasonic pulse-echo inspection [27]. In 1994, Wall and Wedgwood presented a review of the economic benefits to be derived from being able to improve and quantify speed, coverage and reliability of the NDE measurements [28].

In the same year, Schmerr and Thompson at Iowa State University based on their research concluded that modelling of NDE allowed it to be fully integrated in the design and life cycle performance [29]. Two years later in 1996, Meeker, et al. discussed the physical models based on theory of ultrasonic wave scattering that could be used to predict measurements from the flaw signal distributions [30].

In the following year, Wall at the National NDT Centre (NNDTC), Harwell presented a review on modeling of NDE reliability and the application of corrections for human factors [24]. In the same year, an overall review of the POD modeling methodology developed at Iowa State University was presented by Thompson and Meeker [31].

In 1998, Sarkar, et al. combined a deterministic POD model with a statistical model to predict POD at inspection conditions that are different from the original conditions for which experimental data was available [32]. Thereafter in 2001,Meeker, et al. described a novice modeling methodology combining the use of physical modeling and statistical modeling to account for other important factors that are not included in the physical model (e.g., human factors, unavoidable changes in inspection system properties) [33].

FUTURE OF POD: MODEL ASSISTED POD

In recent years, both Iowa State and the NNDTC have continued developing models to determine POD results. Researchers at Iowa State has formed the Model Assisted POD (MAPOD) working group in 2004, with the collaboration of the U.S. Air Force Research Laboratories (AFRL), the Federal Aviation Administration (FAA) and the NASA, to explore computational POD opportunities. Likewise the NNDTC, have continued to develop some interesting POD models for composites, magnetic flux leakage in floor scanners and other POD applications in the offshore industry [34].

Over the past three decades, the POD concept and methodology have gained widespread acceptance and continuing improvements have enhanced its acceptance as a useful metric for quantifying NDE capabilities. The number of publications dealing with the topic POD has increased significantly during the last few years as depicted by Fig.3. This fact indicates the popularity and importance of the POD concepts in the NDE domain [35].

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	CIVA	simSUNDT	UTSIM
Simulation Range	Calculating ultrasonic fields in components and the interaction between ultrasonic fields and flaws.	Calculating ultrasonic fields in components and he interaction between ultrasonic fields and flaws.	Calculating ultrasonic fields in components and the interaction between ultrasonic fields and flaws.
Probes	Single element, dual element, Tandem, TOFD, Focused, Contact, immersion, phased array.	Contact, Immersion	Contact.
Components	Components can be planar, cylindrical, conical, spherical, elbow or complex shape. Materials of components can be metallic, fiber composites or granular composites.	Mainly components are planar objects. Materials of components can be isotropic or anisotropic.	Components can be any complex shape. Materials of components must be isotropic.
Flaws	Calibration defects: spherical pores, side-drilled holes, flat-bottom and hemispherical holes. Planar defects, of any size and orientation, rectangular or semi elliptical.	Volumetric defects: spherical cavity, spherical inclusion, spheroidal cavity, side-drilled hole; Crack-like defects: circular crack, rectangular crack, strip-like crack, surface breaking strip-like crack.	Many different types of defects, including small planar defects, and so on.
Application	Analyzing the experimental data, enhancing the location and characterization of defects. Design and optimization of inspection methods, especially for the phased array probes. CIVA can help to determinate the delay laws and shape of phased array probes.	Optimizing angle, frequency and bandwidth of suggested probes of real inspection. Justifying acceptance range of these parameters.	Predicting ultrasonic fields in complex geometries and echoes from defects. Optimizing transducer locations. Training.

Table 2: Comparison of various UT simulation tools [36].

At present, various approaches are used to predict POD curves of various NDE methods by computational means. By making use of these approaches various NDE simulation tools such as CIVA, Imagine 3D, simSUNDT, UTSIM, VirtualNDE etc. are available in the market. The comparison between the three most commonly used UT simulation tools is given in Table 2.

The advantage of using these simulation tools is that they are relatively easy to use, less time consuming and less expensive. Typically, input to these models is to vary the parameters such as scan rate, defect orientation, threshold setting etc. to obtain consistent estimates of the POD and Probability of False Alarm (POFA) [34]. Another advantage of model calculations is that these are the only source of the POFA data, as there is very little experimental data on the POFA [34]. Furthermore, modelling also allows assessment of historical data, optimisation at the design stage and allows valuable experimental data to be extended to the new applications.

CONCLUSION

Conventional NDE methods are mainly used during in-service inspection to detect the flaws in the welded structure. Since, updating the component's reliability is generally based on the inspection results from NDE; hence, it is necessary to quantify the detection capability of the NDE methods. This quantification is termed as NDE reliability. The aforementioned is mostly assessed based on the largest flaw, which is possible to be missed, rather than the smallest flaw that is possible to be detected. In addition, there is often a large gap between the aforementioned flaw sizes. The flaw size used for expressing NDE reliability is the one having POD of 90%. The aforesaid crack size is known as a90 crack size [6]. Nevertheless, there is certain statistical uncertainty associated with the value of a90, which is represented by stating, a 95% confidence interval. This crack size is represented as a90/95

POD has been widely accepted as a metric for quantifying NDE capability and is expressed as function of crack size, which is represented as POD curve. The historical background and development of POD was outlined in this paper. Until mid 90s, essentially all applications of the POD concept had been empirical. Since, it was an arduous and expensive task to experimentally determine POD curves; thus, now the focus has shifted towards the model assisted POD. The advantage of using these simulation tools is that they are relatively easy to use, less time consuming and more economical. At present various NDE simulation tools are available in the market and in the near future more developments need to be made in the field of computational POD generation.

Author

Arvind Keprate

Research Fellow

University of Stavanger,

Norway.

arvind.keprate@uis.no

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Europe's Leading Conference and Exhibition on New Pipeline Technologies

Almost 500 participants visited the 10th PTC in Berlin

New developments were introduced

Review of the 10th Pipeline Technology Conference 2015 in Berlin

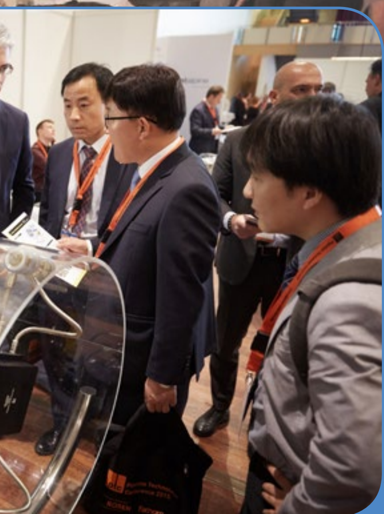
With delegates from 49 different nations with 493 participants including staff and management of 53 international pipeline operators, 47 exhibitors, 10 sponsors, 70 speakers and 12 poster sessions the 10th Pipeline Technology Conference (8-10 June, Berlin) is shaping up to be a pivotal event for the **global pipeline community**.

The purpose of the Pipeline Technology Conference (ptc) is to gather operators as well as technology and service providers on a global basis in order to enhance pipeline technology. Therefore the conference addressed in 13 technical sessions and its Opening Panel Discussion the major industry challenge faced by the pipeline community today. A wide range of recent and future "safety" aspects were presented by experts from international key players form the oil and gas pipeline industry. Their insight and expertise fed directly into discussions and involvement of the participants with live polling.

A technical exhibition accompanied the conference offering the opportunity to more than 30 media partners to be presented in the media lounge during the show. Followed by a poster show, post conference workshops and social programs the delegates took advantage of the sheer wealth of experience available from industry leaders and innovators gaining a comprehensive understanding of key industry issues and new solutions.

The unique Closing Panel Discussion on "German Energy Turnaround" focused on questions surrounding the future of pipelines in a renewable energy age in Germany, Europe and worldwide.

All abstracts and papers of the conference are published on the ptc website and are now publically available for international researchers and scientists from all over the world (www.pipeline-conference.com/abstracts).
For more information visit www.pipeline-conference.com.



to an international audience

Attendees networking at the exhibition

CONFERENCES / SEMINARS / EXHIBITIONS

600+ DELEGATES

50+ EXHIBITORS

55+ DIFFERENT NATIONS

The Pipeline Technology Conference (ptc) and Pipe and Sewer Conference

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The conference will provide panel discussions and special focus sessions on "Pipeline Safety", "German Energy Turnaround", "Challenging Pipelines" and "Offshore Technologies". For the first time the conference will also feature an "Scientific Advances Poster Session" with latest updates on present and upcoming research activities.

ptc will feature lectures and presentations on all aspects surrounding oil, gas, water and product pipeline systems. The exhibition with more than 50 exhibitors will show latest pipeline technologies and products. This years ptc will be held in parallel to the 1st PASC (Pipe and Sewer Conference and Exhibition). Focusing on lower pressure pipes and sewers, the new PASC offers a great opportunitiy for relevant providers to exchange latest technologies and devlopments from this area. Also, PASC provides synergy effects for provider, wo are active in both sections.

For more information kindly visit: www.pipeline-conference.com and www.pipeandsewer.com

"64% of the ptc Delegates are coming from abroad (Europe, Middle East, North America, South America, Asia, etc.)"

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17 Technical Sessions at ptc / pasc 2016

- Integrity Management
- Inline Inspection
- Leak Detection
- Repair / Rehabilitation
- Materials
- Coating / Corrosion
- Pump & Compressor Stations
- SCADA / Automation
- Remote Sensing
- Offshore Technologies
- Planning & Construction
- Trenchless Construction
- Trenchless Rehabilitation
- Legal Assessment
- Inspection
- Asset Management
- Waste Water Disposal

Details about the conference program can be found on the following websites:

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ptc

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After starting as a small side event of the huge HANNOVER MESSE trade show in 2006 in Hannover, the Pipeline Technology Conference developed into Europe's largest pipeline conference and exhibition. Since 2012 the EITEP Institute organizes the ptc on its own and moved the event to Berlin in 2014.

IN PARALLEL TO

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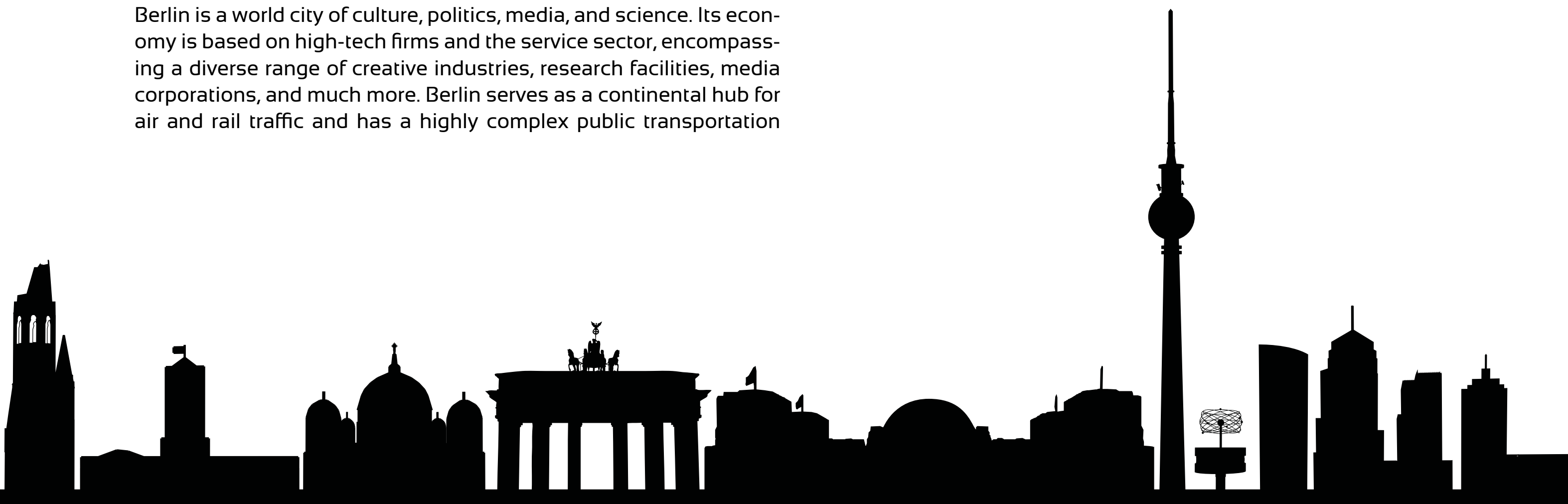

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CONFERENCE

Monday, 23 May

10:00

- Opening
- Key Note Speech
- Plenary Session "Southern Gas Corridor"

Pipeline Track 1	Pipeline Track 2	Pipeline Track 3	Construction Track	Pipe and Sewer Track
LUNCH BREAK				
Session 1: Integrity Management	Session 2: Coating / Corrosion	Session 3: Leak Detection	Session 10: Legal Assessment (Discussion)	Session 13: Inspection
COFFEE BREAK				
Session 1: Integrity Management	Session 2: Coating / Corrosion	Session 3: Leak Detection	Session 11: Planning & Construction	Session 13: Inspection
GET TOGETHER				

Tuesday, 24 May

09:00

Pipeline Track 1	Pipeline Track 2	Pipeline Track 3	Construction Track	Pipe and Sewer Track
Session 4: Inline Inspection	Session 5: Pump & Compressor Stations	Session 6: Remote Sensing	Session 11: Planning & Construction	Session 14: Asset Management
COFFEE BREAK				
Session 4: Inline Inspection	Session 5: Pump & Compressor Stations	Session 6: Remote Sensing	Session 12: Trenchless Construction	Session 14: Asset Management
LUNCH BREAK				
Session 7: Materials	Session 8: SCADA / Automation	Session 9: Offshore Technologies	Session 12: Trenchless Rehabilitation	Session 15: Waste Water Disposal
COFFEE BREAK				
Session 7: Materials	Session 8: Repair / Rehabilitation	Session 9: Offshore Technologies		
DINNER INVITATION				

Wednesday, 25 May

09:00

- Plenary Session "World Pipeline Outlook: New Technologies in Operation"

COFFEE BREAK

- Closing Discussion "New Technologies for the Pipe-related Transportation of Various Goods and Media"
- Closing Remarks

LUNCH BREAK

14:00

Post-Conference Workshops
(to be announced)

Seminars
(to be announced)

EXHIBITION

09:00 – 14:00

All breaks and lunches take place within the exhibition area

CONFERENCES / SEMINARS / EXHIBITIONS

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Pipeline Operations and Maintenance	11-14 April 2016	Manama, Bahrain
Interpipe 2016	12-14 April 2016	Langfang, China
3rd International Pipeline Coating Conference	20-21 April 2016	Dubai, UAE
11th Pipeline Technology Conference (ptc)	**23-25 May 2016**	**Berlin, Germany**
1st Pipe And Sewer Conference (PASC)	**23-25 May 2016**	**Berlin, Germany**