Monitoring of Flexible Pipes
State of the Art

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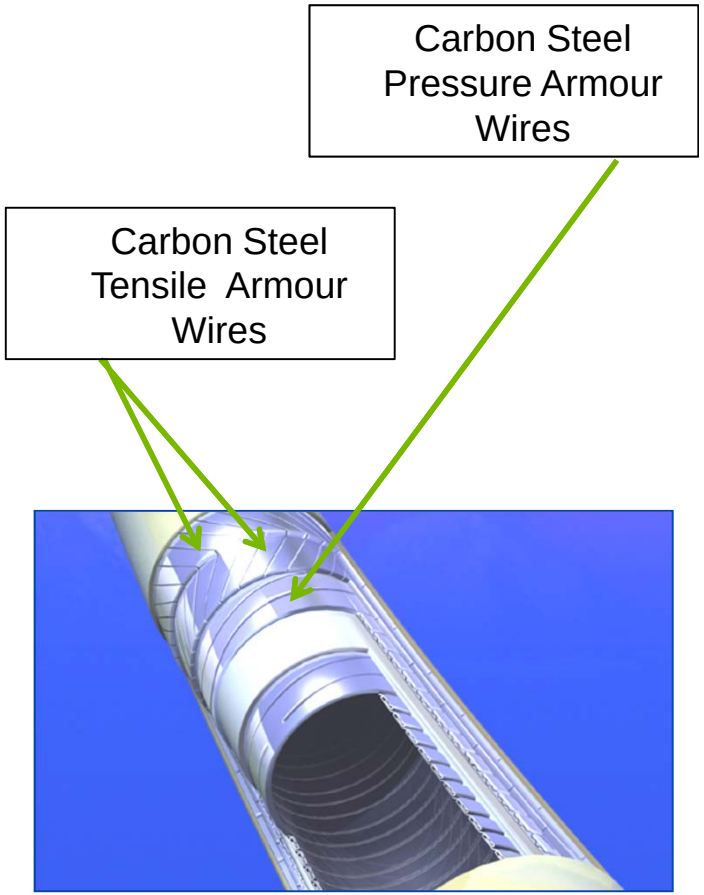
Fundamentals and the case for Monitoring

Flexible Riser Failure Modes

Overbending

Overbending of a flexible pipe can result in :

- **Excessive strain in polymer sheaths**
- **Unlocking of the pressure armour wires leading to loss of pressure containment**



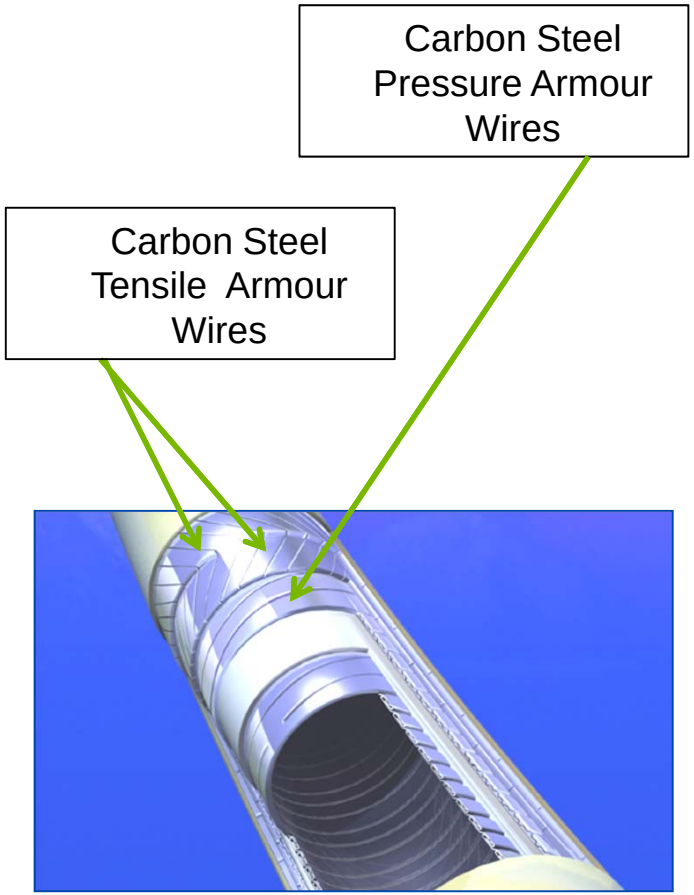
Flexible Riser Failure Modes

Pressure and Tensile Armour Wire Fatigue

Wire Fatigue Life = Fn (…..

- **Mean and Cyclic Wire Stress,**
  - **Residual manufacturing stress**
  - **Operating pressure and tension**
  - **Local curvature and tension variation**
    - **Riser configuration**
    - **Vessel motion**
    - **Wave/current environment throughout field life**
- **Wire material fatigue properties,**
  - **Basic fatigue properties**
  - **Annulus corrosive environment**
    - **Permeation through internal polymer sheath**
    - **Condition of external sheath**

Many interacting mathematical models + Factor of Safety of 10 gives conservative design



Flexible Risers

The case for monitoring

As we push products closer to their limits :

- **Deeper water**
- **Higher pressures**
- **Longer field lives**

Reduced reliance on multiple mathematical models and stacked conservatisms can :

- **Enable design for more onerous conditions**
- **Allow assessment of “consumed” fatigue life at any time**
- **Facilitate field life extensions based on known stress histories**
- **Aid decision making process following an unplanned event**

Monitoring of certain parameters can replace the reliance on mathematical models with actual performance measurement.

Flexible Risers

The case for monitoring

Critical parameters to be monitored in a flexible riser include :

- **Continuous Online Real Time Curvature variation**
  - **to assess overbending and fatigue life consumption**
- **Annulus condition (flooding, gases)**
  - **more accurate calculation of fatigue life consumption**
- **Armour wire break detection**
  - **early warning system**

Established and Emerging Monitoring Technologies and Products

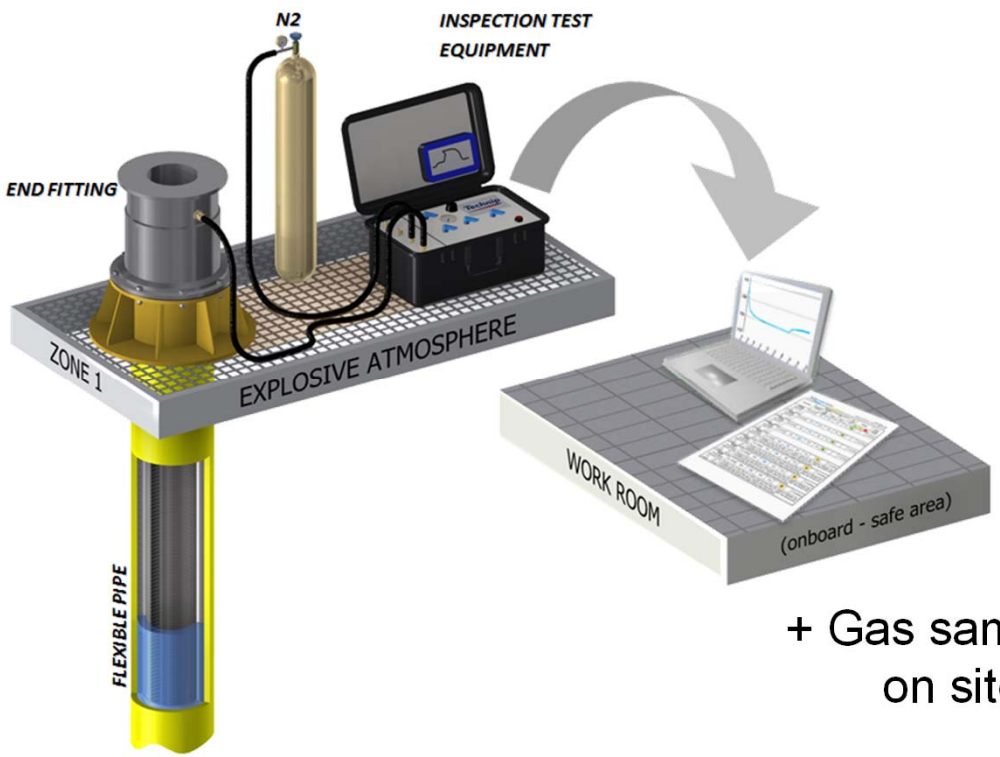
Flexible Pipe Monitoring
Established and Emerging Technologies

Surveillance	Monitoring
Annulus Condition	DTS for flooding detection Annulus vent gas monitoring
Armour wire Condition	Acoustic Emission
Fatigue	Curvature monitoring Top tension monitoring

Flexible Pipe Monitoring

Annulus condition inspection

- **Advanced Riser Annulus Test Services**



+ Gas sampling on site

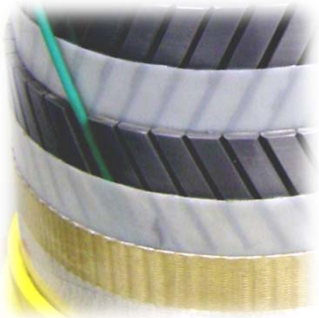
More than 1000 risers inspected in 15 years

A mature and robust process that has been completely repackaged for optimal deployment in a single cabinet

Flexible Pipe Monitoring

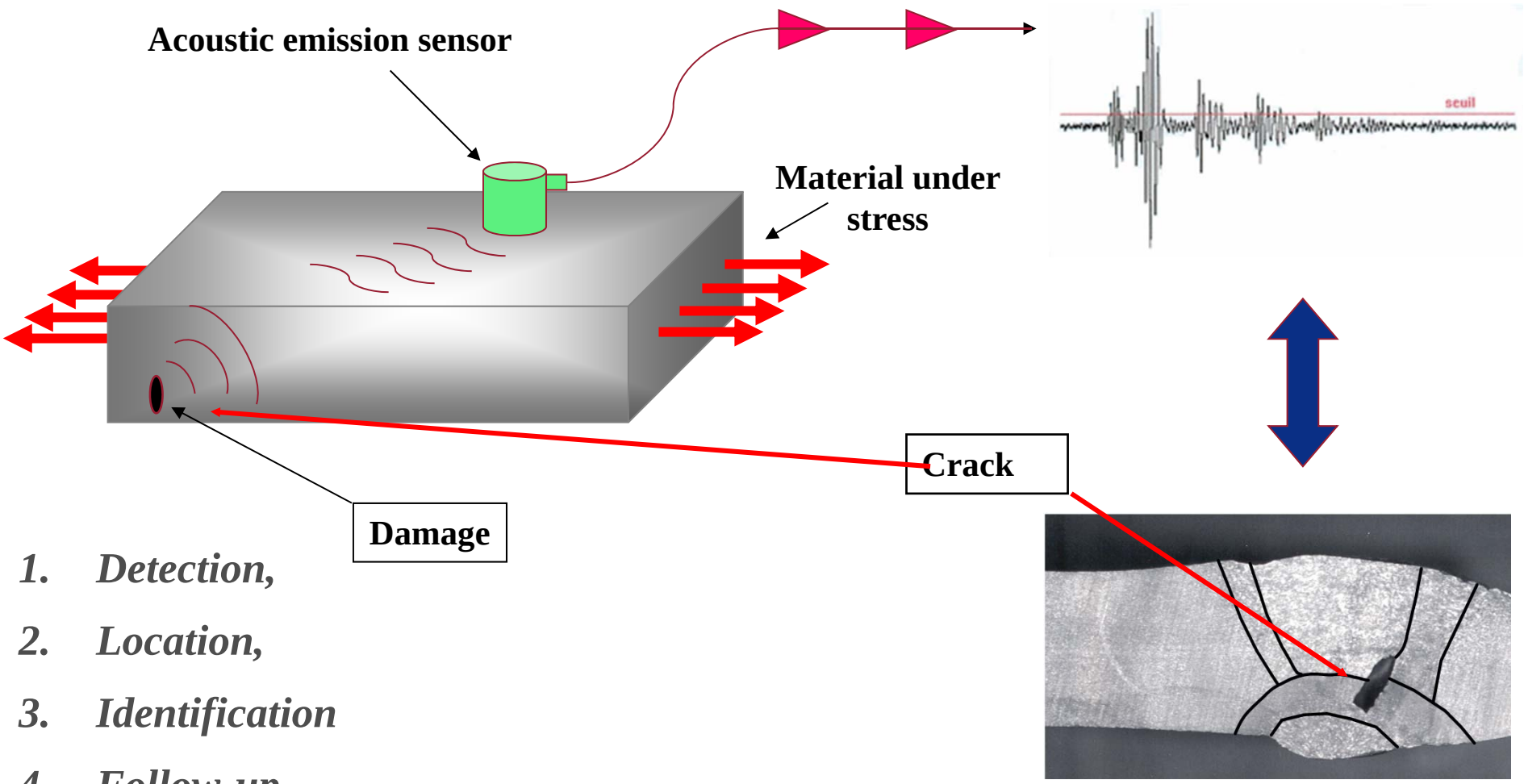
Annulus Flooding Detection using Distributed Temperature Sensing (DTS)

- **DTS is a mature technology for continuous annulus temperature measurement using fiber optics inserted within pipe armour layer**
  - Deployed on Dalia IPB's since 2007
  - Deployed and fully commissioned on Islay Trace Heated Pipe in Pipe in 2012
  - Deployed on Papa Terra 2014
- **Enhanced development of DTS can interpret the level of flooding of a flexible pipe annulus, provides inputs for:**
    - Flow assurance
    - Annulus flooding detection
- **Status**
    - In-situ full scale test validation on-going in Brazil



Flexible Pipe Monitoring

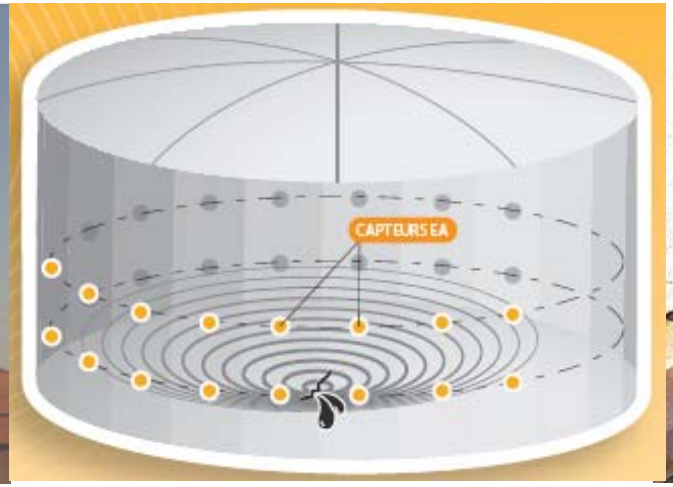
Acoustic Emission NDT to detect Armour Wire Breakage



1. *Detection,*
2. *Location,*
3. *Identification*
4. *Follow-up*

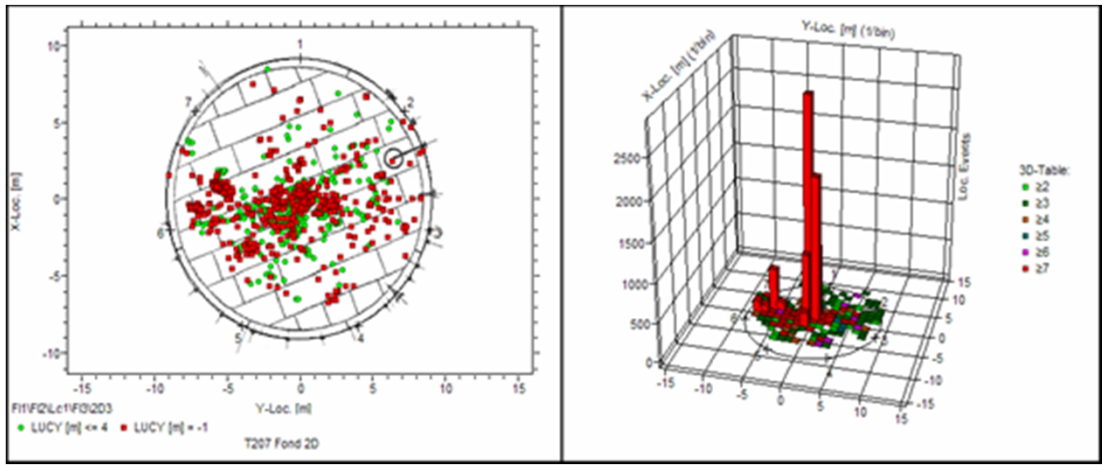
Flexible Pipe Monitoring

Acoustic Emission NDT to detect Armour Wire Breakage



A special location algorithm calculates and visualizes the exact position of the sources of acoustic emission and thus of the damages in the tank floor.

in situ inspection, in service *with stored liquid for lower* ***costs.***



Leakages **Detection**

Corrosion Detection

Flexible Pipe Monitoring

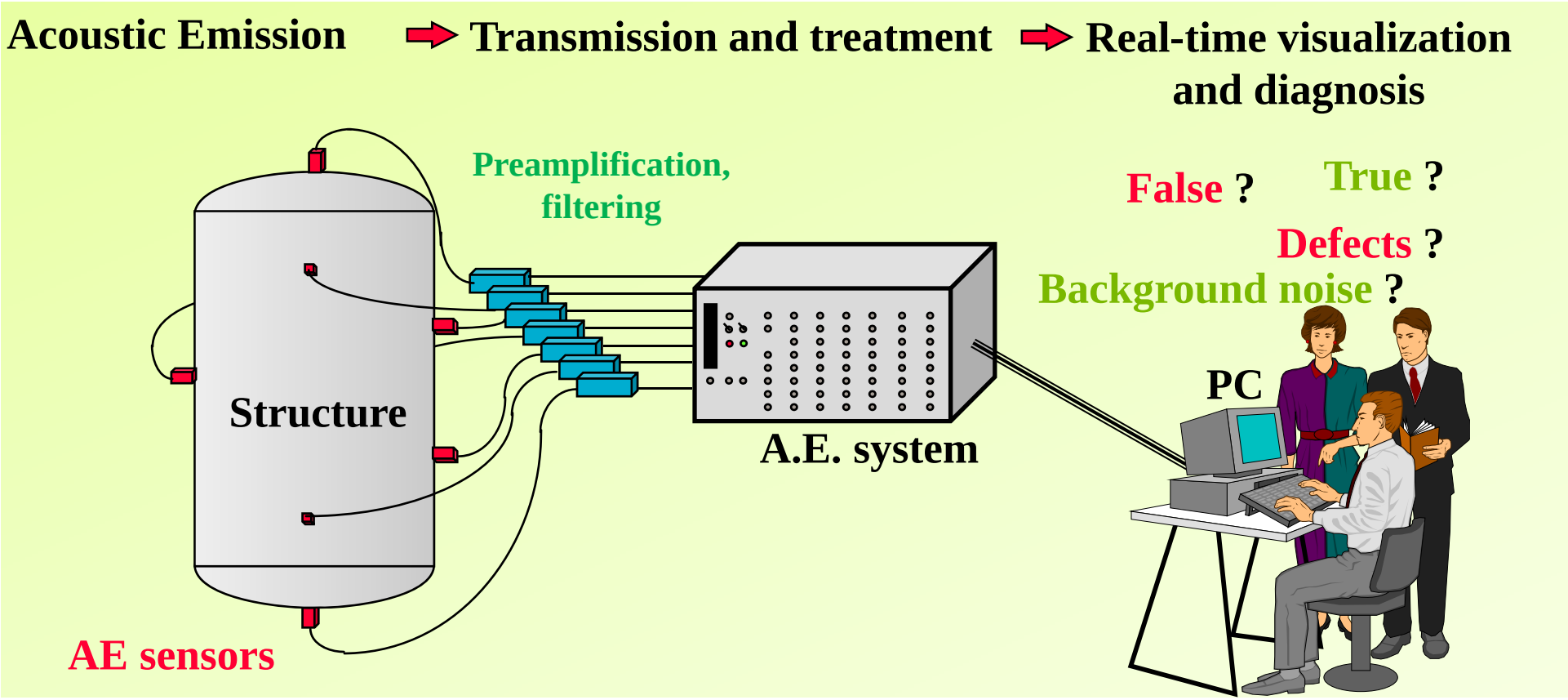
Acoustic Emission NDT to detect Armour Wire Breakage

BSEI Decision Nº09-102, June 29, 2009

Concerning the replacement of hydraulic proof test during the periodic re-qualification of certain pressure equipment, by a gas pressure test controlled by acoustic emission.

ASME: Section V, Article 11 Acoustic Emission Examination of Fibre-Reinforced Plastic Vessels.

ASME: Section V, Article 12 Acoustic Emission Examination of Metallic Vessels during Pressure Testing



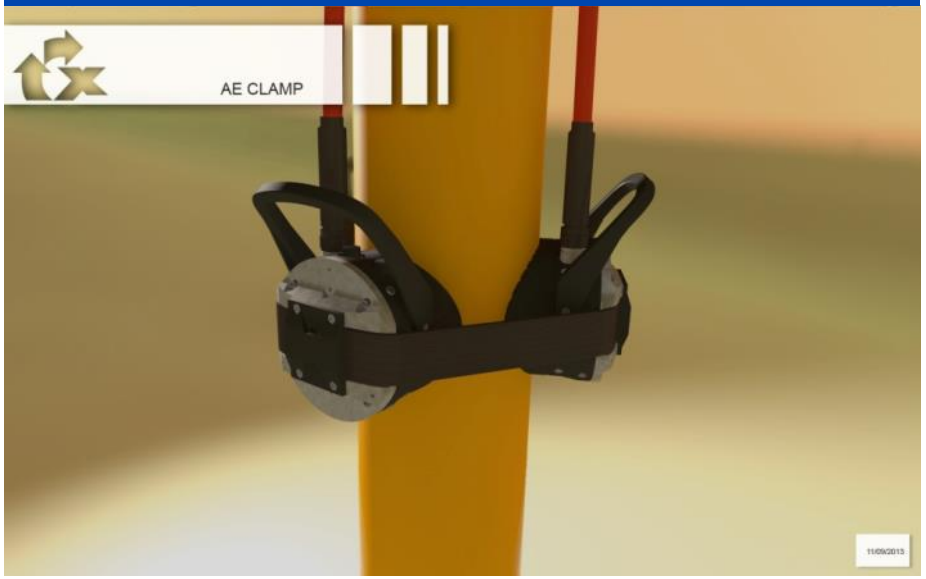
Flexible Pipe Monitoring

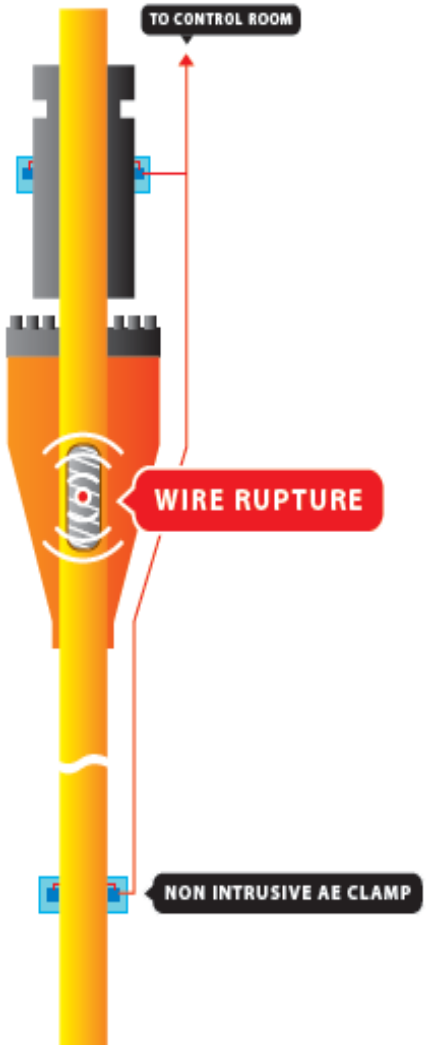
Acoustic Emission NDT to detect Armour Wire Breakage

Armour break detection in risers

Purpose & Benefits:

- Detection of tensile armour wire rupture
- Non intrusive & retrofittable system
- Real time riser integrity assessment
- New & existing risers
- Pilot system ready for deployment Brazil

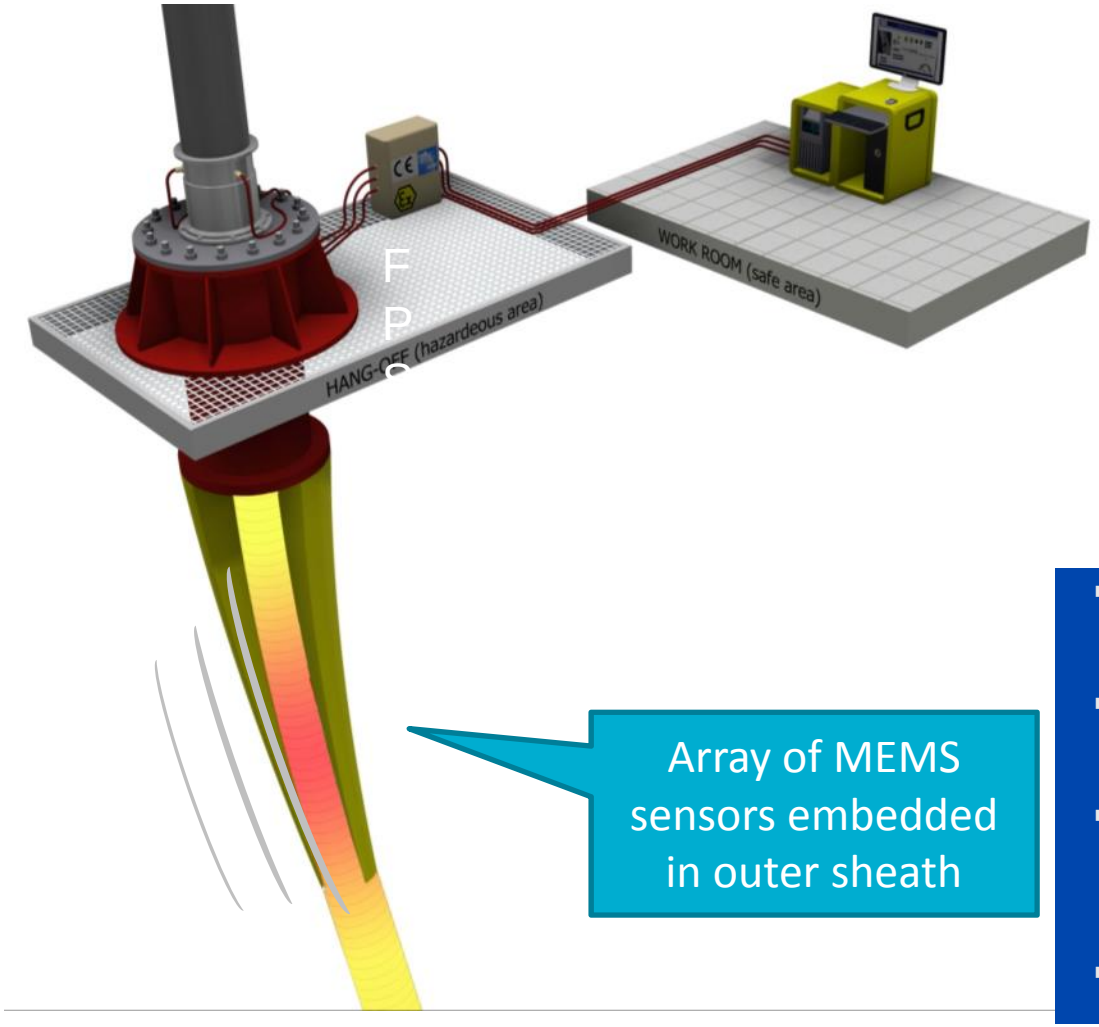


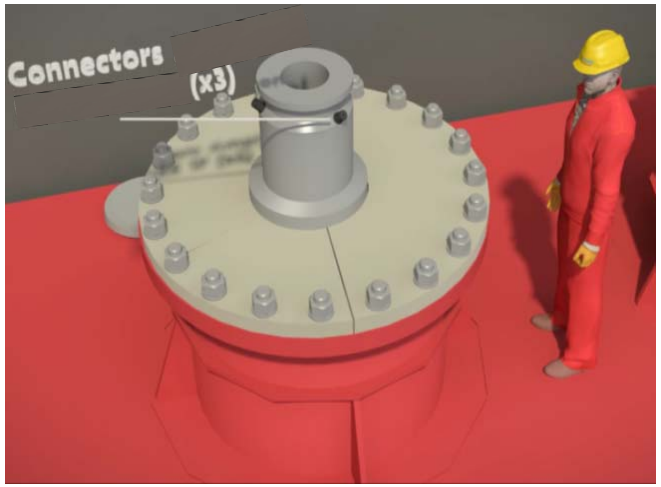


Flexible Pipe Monitoring

MORPHOPIPE – MEMS Based Riser Curvature Monitoring

Overview of configuration





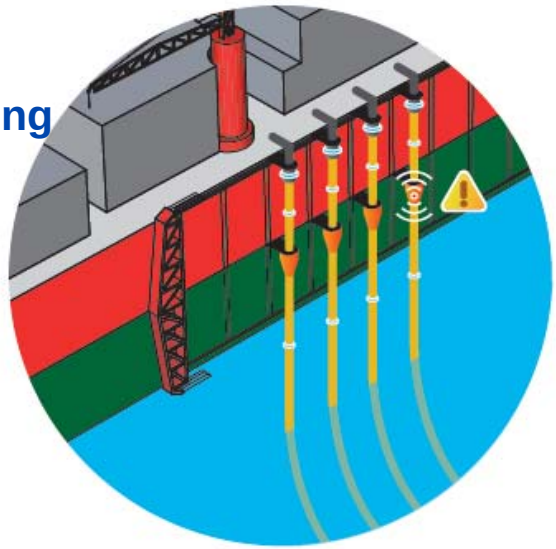
Array of MEMS sensors embedded in outer sheath

- Array of MEMS embedded around circumference of sheath
- Each can report back its own local position and inclination continuously
- Algorithms to calculate pipe curvature based on relative positioning between all sensors in array.
- Prototype qualification testing on-going

Flexible Pipe Monitoring

MORPHOPIPE – MEMS Based Riser Curvature Monitoring

Curvature measurements



- **Real Time, Continuous Monitoring of 3D curvature**
  for extreme curvature detection
  and contribution to fatigue re-assessment
- **Integrated to flexible pipe in topside dynamic area**
  with smart microsystems

⇒ **Alarm for operators:** Over curvature and abnormal shape detection

⇒ **Data** for fatigue analysis of topside dynamic section

Accurate and valuable information for fatigue analysis and dynamic behavior of flexible pipe

Inspection and Integrity Management Program

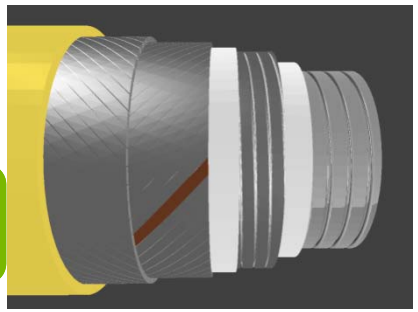
- **A reliable subsea inspection and integrity management service require expertise in several domains:**
  - **Flexible pipes design and manufacturing**
  - **Inspection technologies applied to multilayers and multi material structures**
  - **Subsea equipment deployment**

- **Review and development of next-generation technologies ongoing. Leveraging on 40 years of product and application experience.**

Ultrasonic testing

Electromangetic

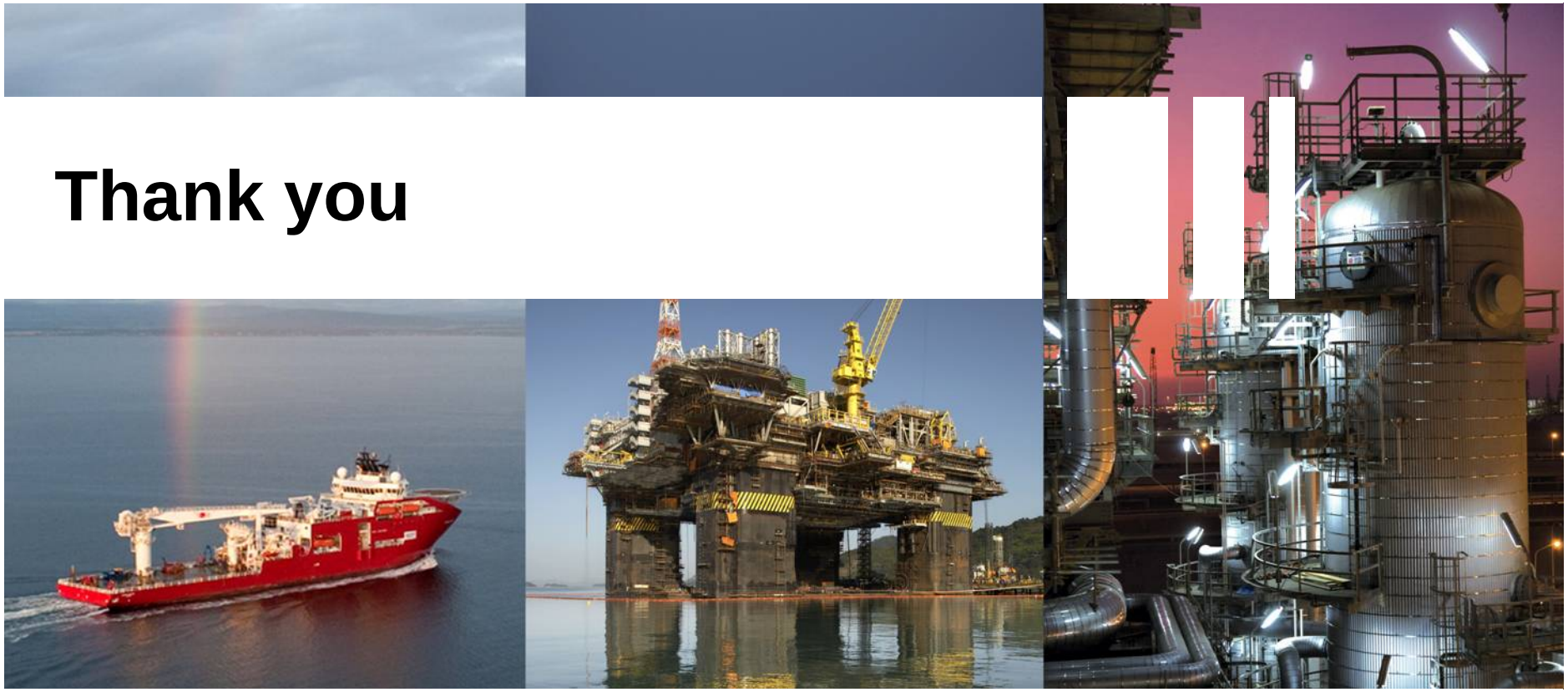
Radiography



Conclusion

- **Integrity Monitoring and Management becoming more of an imperative as operating envelopes are extended**
- **Monitoring technologies and philosophy must be integrated at early product design stage**
- **Existing monitoring and inspection services can provide valuable information**
- **Emerging monitoring technologies, combined with product design and manufacturing expertise will facilitate comprehensive integrity management programs.**

Thank you



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