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ICORR ABERDEEN BRANCH WELCOME

2019 CORROSION AWARENESS DAY

ABZ Branch Chair: Stephen Tate

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ICorr Aberdeen Branch Welcome

Thank you for participating in the Aberdeen ICorr Corrosion Awareness Event.

We hope that you find the Day of benefit and that it will assist you in your understanding of the impacts of Corrosion.

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2019 Corrosion Awareness Day

This course is hosted by: ICorr Aberdeen through kind assistance of its local / national sponsors.

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2019 Corrosion Awareness Day

Our Local Branch / Mtg. Programme Sponsors are:

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ICORR GOLD SPONSORS - Corrpro Companies Europe Ltd, Helvetica Technical Consulting Sagl, Midis Energy Services Ltd, Miller Fabrications Ltd, Pipeline Technique, Pittsburgh Corning.

ICORR SUSTAINING SPONSORS - CAN Offshore, Denholm Industrial Services Ltd, Element Material Technology, ICR, Lake Chemicals & Minerals Ltd, Lux Assure Ltd, Oceaneering, Plant Integrity Management, R&R Corrosion Ltd, Sonomatic Limited.

AGAINST ALL ODDS…

The ABZ Branch has trebled its Sponsorship in the last 3yrs.

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Our Local Branch / Committee is:

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For the coming Session Committee is: **Pls Stand.**

- **Chair**: Mr. Stephen Tate
- **Vice Chair**: Dr. Nigel Owen
- **Secretary - External**: Mr. Alistair Seton, Past Chair
- **Secretary - Internal**: Mr. Hooman Takhtechian
- **Treasurer/Finance Officer**: Mr. Bryn Roberts
- **Event Co-ordinator**: Mr. Amir Attarchi
- **University Liaison and CPD Officer**: Ms. Zahra Lotfi
- **Website Officer**: Dr. Yunnan Gao, Immediate Past Chair
- **Committee Members**: Dr. Muhammad Ejaz (Past Chair) and Mr. Jonathan Segynola.

With Special thanks to Dr Yunnan Gao, for his 2yr Service as Past Chair.

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Corrosion is of Course: A daily problem and our local branch sponsors support our ongoing education programmes with regular meetings here at the **Palm Court and RGU**.

Additionally there are 2-3 Industrial Visits ea. Yr.

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ICR - 2019

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Corrosion Happens Every Day !...4% GDP Annually

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THE ‘BROKEN’ BRIDGE OF ITALY: Severe External Corrosion

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THE ‘NEARLY BROKEN’ BRIDGE OVER THE FORTH: Cable Corrosion

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THE ‘NEARLY BROKEN’ BRIDGE OVER THE TAY: Corrosion of Piers

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The primary objective is to: improve understanding of corrosion processes and to raise awareness of corrosion management issues.

CAD Events have been run regularly by ICorr Aberdeen over the last 10 yrs.

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ICorr Aberdeen Events
Corrosion Awareness Course

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2019 Corrosion Awareness Day

This Year - A full-day + Evening Course,

comprising a number of lectures, providing essential information on corrosion principles and mechanisms of MIC. (**microbially induced**) corrosion control:

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Your Programme Today
Specifically Focusses on Pipelines

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Many North Sea Pipelines Have Been Lost Due To 'MIC Type' Corrosion

Esp. Oil Export and Water Injection

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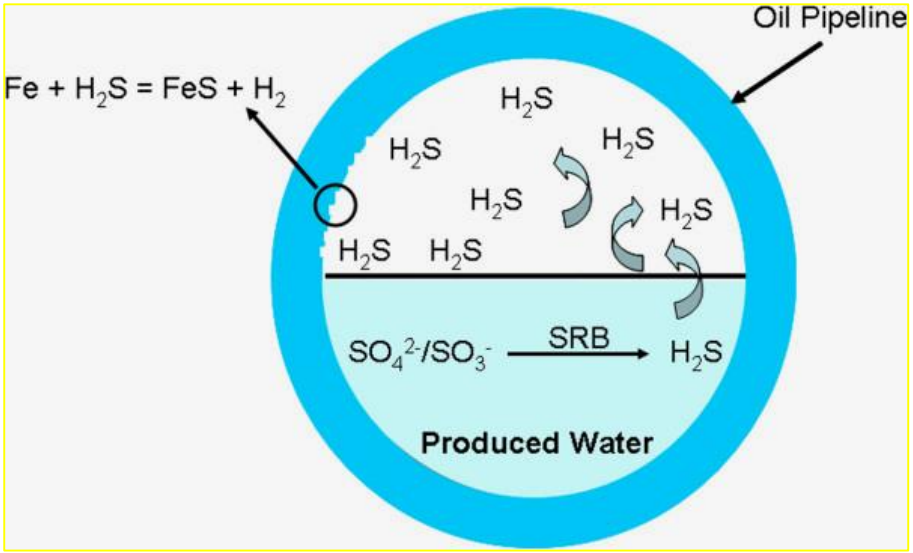

MIC INTERNAL:

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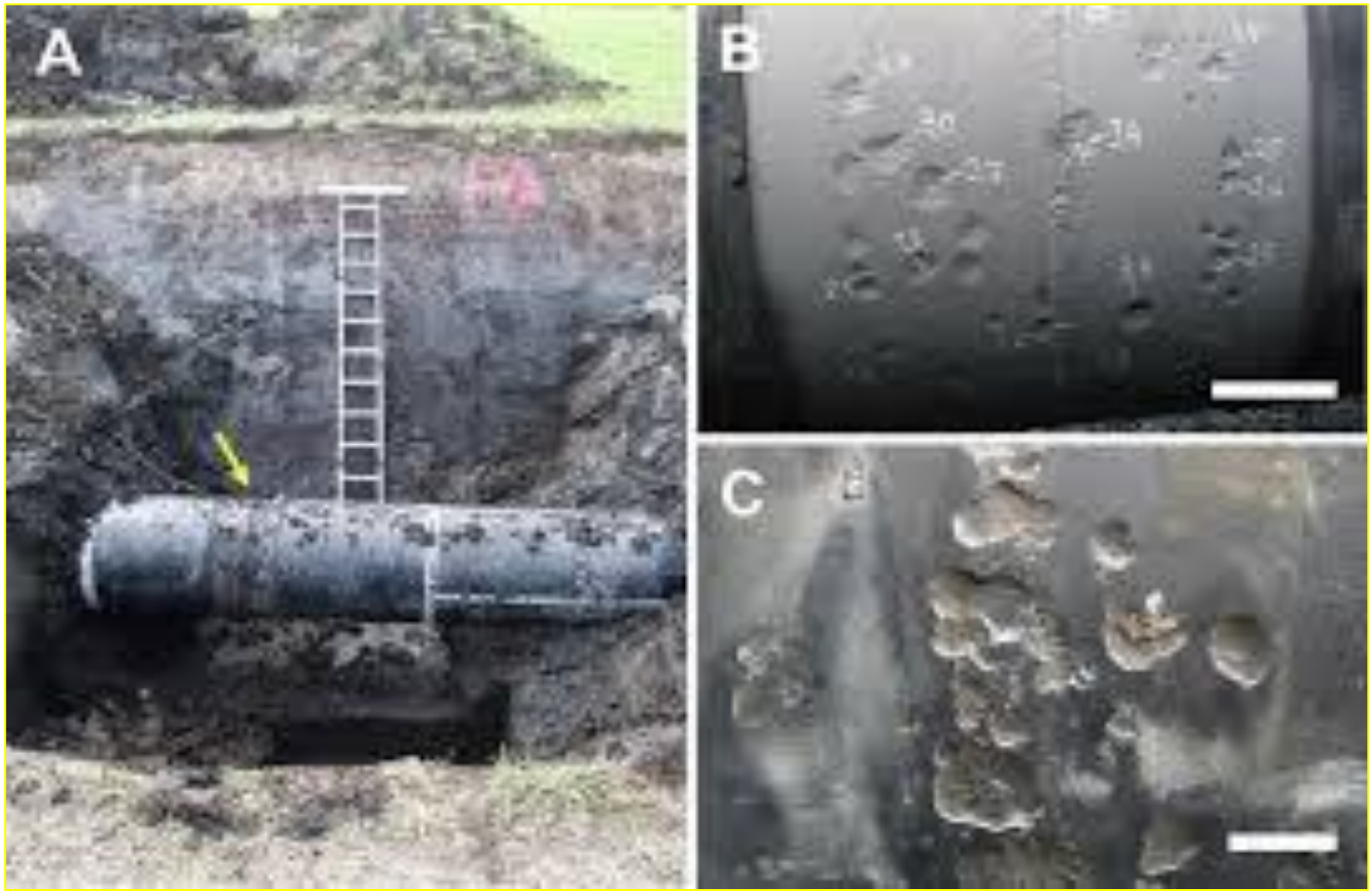

MIC EXTERNAL:

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2019 / 2020 Branch Programme

Continuing Education

Copy In Every Delegate Pack.

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ICorr Aberdeen Branch 2019/2020 Programme of Events

Rev 0, 23/08/2019

Date	Event Type	Speaker (s) / Company	Topic (s)	Time	Venue
Tuesday 27/08/2019	2019 Corrosion Awareness Day (CAD)	ROSEN – Speakers (Various)	**Annual ICorr Aberdeen / ABZ Corrosion Awareness Day:** Programme, (ICorr 2019/2020 Chair). Speaker 1 (ICR Integrity – Carol Devine) – My Life in MIC. Speaker 2 (Shell – Mabel Ntim) – MIC Experience from a Global Operator. Speaker 3 (DTI – Laura Tiano) – Sampling, Analysis and Monitoring of Pipelines for MIC. Speaker 4 (ROSEN – Steven Loftus) – Modelling of Pipeline Susceptibility to MIC. Speaker 5 (DTI – Lone Tang) – Chemical Management of Pipeline MIC: Strategies for Improved Mitigation. Speaker 6 (ROSEN – Daniel Sandana) – Inspecting for MIC. Speaker 7 (ROSEN – Ian Laing) – Cleaning and Mitigation for MIC.	Event to start at 09:00 and finish at 20:00. Special Evening Session: 18:00; Presentations at 18:30.	Palm Court Hotel, 81 Seafield Road, Aberdeen, AB15 7YX
Tuesday 03/09/2019	Industrial Visit - 1	NCIMB - Dr Daniel Swan	**An integrated molecular approach to microbial monitoring. Tour and demonstrations, (rotating in groups of 10):** • The National Collection of Industrial Food and Marine Bacteria: Most people are quite surprised to learn that such a thing exists but our collection includes bacteria isolated from all kinds of places including hippopotamus bathing water and the dental plaque of a baboon. Bacteria from the collection have been used in a broad range of research and industrial applications, and the collection has also had a long-standing connection with the oil and gas industry. • Most Probable Number (MPN) demonstration. The importance of including sessile and planktonic samples and the issue of NORM contaminated coupons. • Molecular lab – demo of what is involved in the different molecular techniques.	18:00; Presentation at 18:30.	NCIMB Laboratories, Ferguson Building, Craibstone Estate, Bucksburn, Aberdeen AB21 9YA
Tuesday 24/09/2019	Joint Meeting with TWI	ROSEN - Daniel Sandana	**SCC on Offshore Assets with emphasis on Weldments and HISC.**	Sign in & Network from 17:45; Complementary Buffet from 18:00; Presentation at 18:30.	RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB10 7GJ
Tuesday 29/10/2019	ICorr Technical Event	ICORR UK + RAWWATER: (Various)	**Presidents Lecture + Reservoir Management / H2S Mitigation.** Speaker 1: ICorr - Growing our Membership and ICorr Awards - Call for Nominations. Speaker 2: "An understanding of Reservoir Souring and Mitigation"	Sign in & Network from 17:45; Complementary Buffet from 18:00; Presentation at 18:30.	RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB10 7GJ
Tuesday 26/11/2019	Joint ICorr/IOM3 Event	BP/BISN (Various)	**Application of Bismuth based alloys to address Oilfield challenges.** Speaker 1: Paul Carragher (BISN). Speaker 2: Lance Underwood (BISN) Speaker 3: Angus MacLeod (BP).	Sign in & Network from 17:45; Complementary Buffet from 18:00; Presentation at 18:30.	RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB10 7GJ
Tuesday 28/01/2020	Joint EI/ICorr Technical Event	SETS (Various)	**Structural Integrity Issues:** Under-deck, air-gap, splash zone deterioration (of conductors, caissons and risers). Speaker 1: Greg Law. Speaker 2: Chris Tierney.	Sign in & Network from 17:45; Complementary Buffet from 18:00; Presentation at 18:30.	RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB10 7GJ
Tuesday 25/02/2020	ICorr Technical Event	DNV (Various)	**2 Key Areas of RBI:** Paper 1 - PSVs are classed as safety critical when protecting hydrocarbon containing equipment and, even on non-hazardous services are always safety related. Pressure Safety Valve RBI will be discussed using Half a Billion Hours of Data. Paper 2 - For FPSO cargo tanks the main degradation threats are fatigue cracking and corrosion / coating degradation. This presentation gives an overview of DNV GL methods for carrying out an RBI assessment for each of these threats and how they may be used to develop an optimized inspection schedule. Paper 1 Speakers: John Morgan / Chris Bell. Paper 2. Speaker: David Baxter	Sign in & Network from 17:45; Complementary Buffet from 18:00; Presentation at 18:30.	RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB10 7GJ

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Date	Event Type	Speaker (s) / Company	Topic (s)	Time	Venue
Tuesday 31/03/2020	Industrial Visit - 2	Oceaneering (Various)	**Industrial Visit - An Alternative / Interactive Industrial Event.** Ian Drummond as Lead, will be joined by experienced Integrity Professionals / Advance NDT Technologists who will be available for around 60 mins, to take live Integrity related questions from the Audience, (which will appear on a large / high vis. screen behind the Panel for Discussion by all).	Event to start at 18:00; Visit to start at 18:30	Oceaneering, Aker Solutions Building, Aberdeen Airport, Building 1, Dyce Drive, Aberdeen, AB21 0BR.
Tuesday 28/04/2020	Joint ICorr/MCF Event	Economic Engineering Ltd. Alan Hunter	**Economic Literacy and Competency.** O&G Corrosion & Materials Engineers need to be economically literate, as well as technically advanced and competent. The basis of a methodology for commercial success will be proposed and applied to the O&G Integrity & Corrosion Management Sector. Speaker: Alan Hunter	Event to start at 17:30; Presentation to start at 18:00	Palm Court Hotel, 81 Seafield Road, Aberdeen, AB15 7YX
Tuesday 26/05/2020	IOAM - Institute of Asset Management	Adam Lea-Bischinger	**6 Core Elements of Asset Management.** The work of IOAM and the Development and Roll-out of ISO 55000 which defines Terminology, Requirements and Guidance for Implementing, Maintaining and Improving an Effective Asset Management System including examples of UK Companies operating the ISO 55000 System.	Sign in & Network from 17:45; Complementary Buffet from 18:00; Presentation at 18:30.	RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB10 7GJ
Tuesday 25/08/2020	Joint ICorr/NACE Event 2020 Corrosion Awareness Day (CAD)	PETROFAC (Various)	**Annual ICorr Aberdeen / ABZ Corrosion Awareness Day:** Programme: Visit one of the most advanced Oil and Gas Training Centres in the world with nine specially designed modules that closely replicate the systems and equipment found on onshore facilities and offshore installations. The Day will include several Practical Demonstrations with Teaching themed on Fabrication and External Corrosion Management. Speakers / Demonstrators: Graham George /Lynne Cairnie Petrofac HSE Fabric Maintenance Training and Competence Team and Mike Hobin of Chevron/NACE (ABZ).	Event to start at 09:00 and finish at 20:00.	Petrofac Training Centre, Forties Road, Montrose, Angus, DD10 9ET

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ICorr Sustaining Sponsors - CAN Offshore, Denholm Industrial Services Ltd, Element Material Technology, ICR, Lake Chemicals & Minerals Ltd, Lux Assure Ltd, Oceaneering, Plant Integrity Management, R&R Corrosion Ltd, Sonomatic Limited.

Note: This Technical Programme is subject to Amendment / Continuous Improvement. Any changes to planned Events, will of course be advised to you.

Should you have any queries, please refer in the first instance to the 2019/2020 Session Chair: Stephen Tate.

Thank You for your continued support of ICorr. Stephen.Tate@external.total.com

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2019 Corrosion Awareness Day
Further Sources of Information

The ICorr Website: Is an excellent resource.

https://www.icorr.org/sources-of-information/

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Further Sources of Information

The BBC Website: Is also an excellent resource.

http://www.bbc.co.uk

Particularly for Corrosion related incidents

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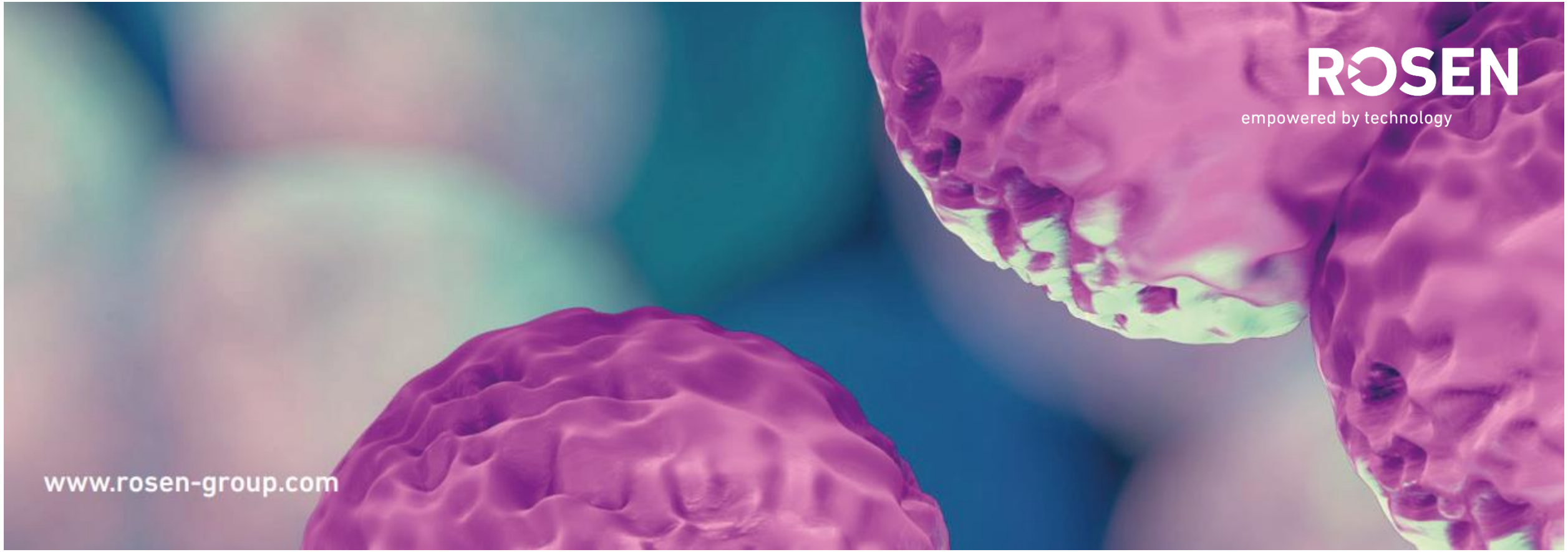
THANK YOU FOR ATTENDING

PLEASE ENJOY YOUR DAY WITH US

And Don’t be Afraid to Ask any Questions.



ICorr – ROSEN

CAD – MICROBIAL INFLUENCED CORROSION

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AGENDA FOR TODAY

0900 0930	**Arrival Tea, Coffee and Breakfast Rolls**
0930 0945	Introduction to ICorr / ABZ Corrosion Awareness Programme
0945 1030	Presentation 1 – My Life in MIC (Carol Devine)
1030 1045	**Tea, Coffee and Shortbread**
1045 1130	Presentation 2 – MIC Experiences from a Global Operator (Mabel Ntim –Shell)
1130 1230	Presentation 3 – Sampling, Analysis and Monitoring of Pipelines for MIC (Laura Tiano – DTI)
1230 1330	**Lunch**
1330 1415	Presentation 4 - Modelling of Pipeline Susceptibility to MIC (Steve Loftus – ROSEN)
1415 1500	Presentation 5 – Chemical Management of Pipelines for MIC: Strategies for Improved Mitigation
1500 1515	**Tea, Coffee and Shortbread**
1515 1600	Presentation 6 – Inspecting for MIC (Daniel Sandana – ROSEN)
1600 1645	Presentation 7 – Cleaning and Mitigation for MIC (Ian Laing – ROSEN)
1645 1650	Presentation of Certificates of Appreciation to Speakers
1650 1700	End of Day Round-up / Close-out / Issue of CPDs

EVENING AGENDA

1830	Synopsis of CAD programme delivered earlier in the day
1930	Grab a beer token and a slice
2015	Panel question time

EXHIBITION	Michael Bruns (ROSEN – Field Products and Services)
	Marc Pages (ROSEN – Integrity Solutions)
COMPETITION	Highest score wins the drone

WHAT IS MIC

- Microbial Influenced Corrosion (MIC) or Bio-corrosion is described as….

  "The initiation and acceleration of materials deterioration due to microbiologically mediated processes"

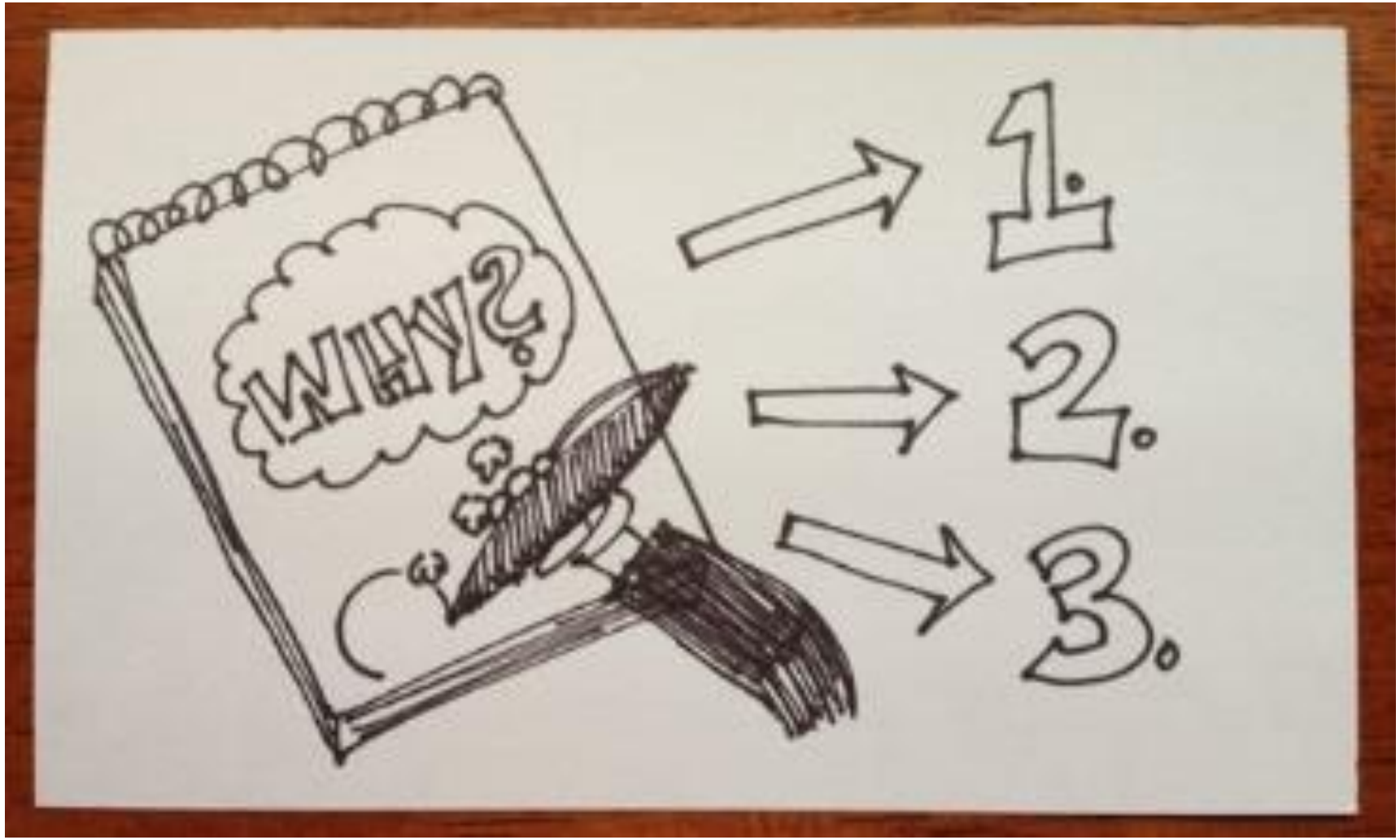
- Microbial species involved …. bacteria, archaea, algae and fungi
  - SRB, APB, IOB, NRB, Methanogens

- MIC has been associated with general & localised forms of corrosion, de-alloying, SSC, SCC, HAC and corrosion fatigue.

- MIC rates typically…. 0.5 to 3 mm/yr (up to 10 mm/yr)

- Its complex and difficult to predict.

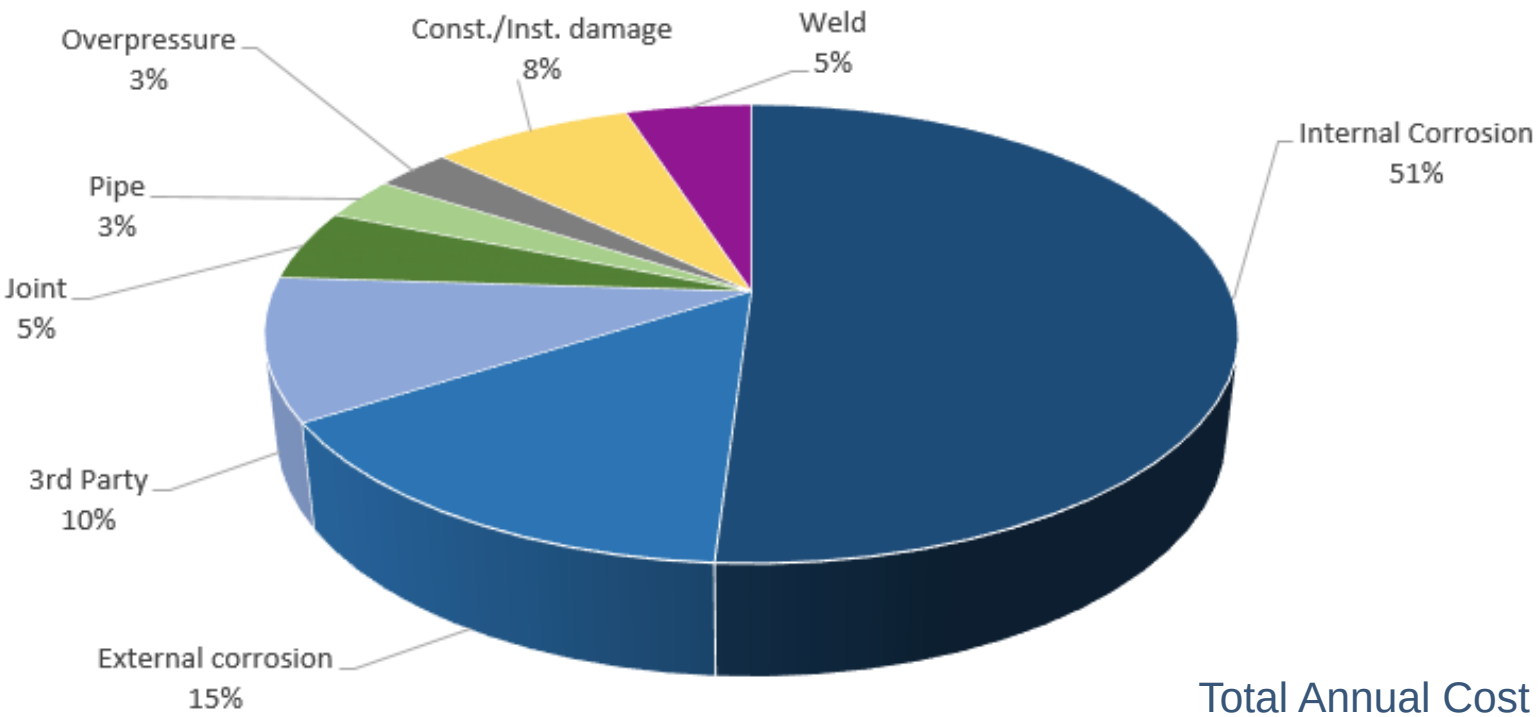
WHY ARE WE HERE TODAY



1. MIC AWARENESS

MIC KPI?

2. THE IMPORTANCE OF MIC

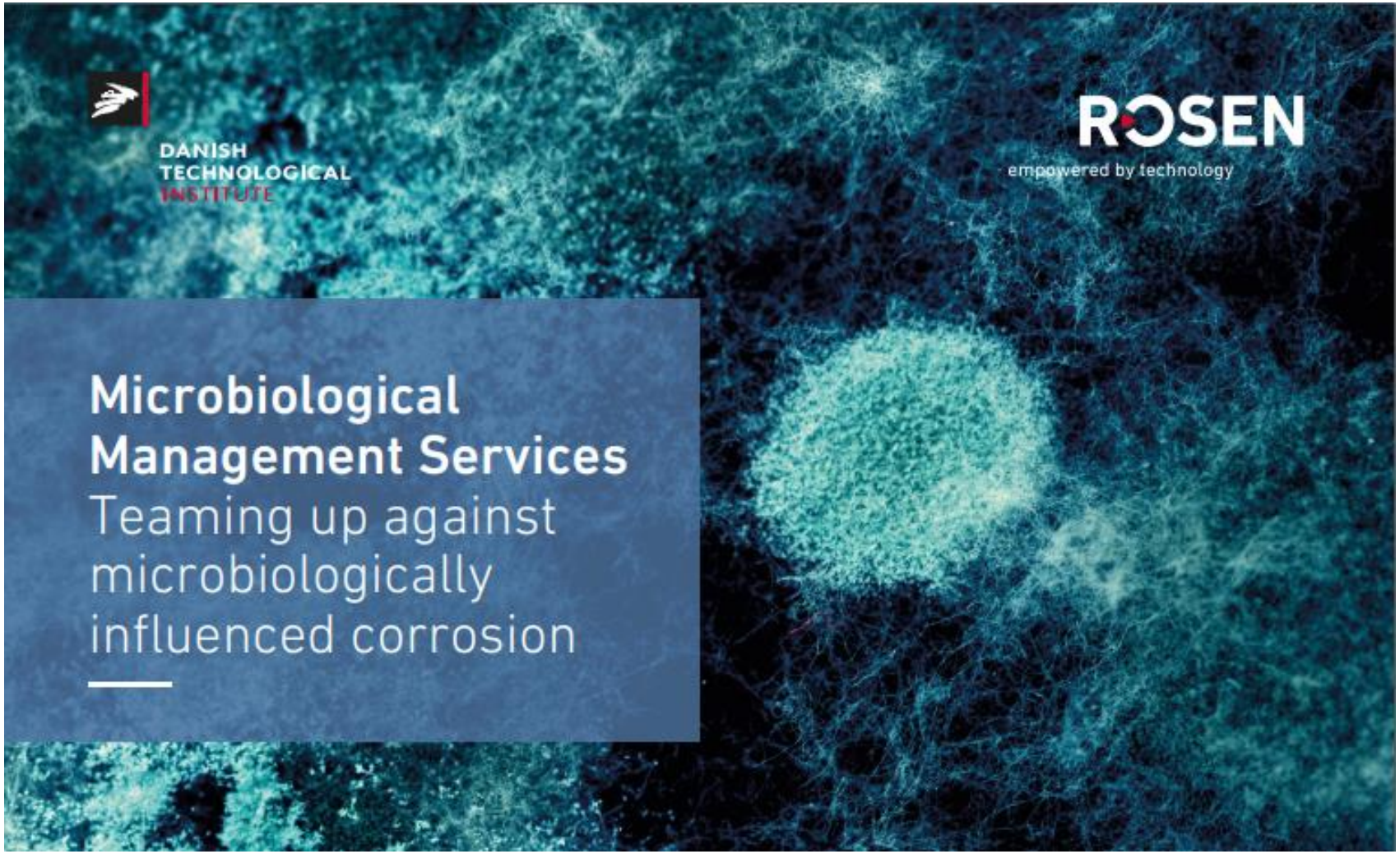


Pipeline & Gas Journal

Total Annual Cost of Corrosion = 14 Billion USD

100 Million USD = MIC

3. ROSEN – DTI…WORKING TOGETHER



HIGHLIGHTING GAPS IN CURRENT PRACTICES

Predictive model for assessing MIC risk, corrosion rate, severity and location along a pipeline

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ICORR ABERDEEN BRANCH WELCOMES

Microbiologically Influenced Corrosion (MIC)

Presented By Dr Carol Devine, Consultant Microbiologist

ICR.




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Dr CAROL DEVINE
CONSULTANT MICROBIOLOGIST

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- BSc (Hons) in Microbiology, University of Aberdeen
- PhD in Subsurface Molecular Microbial Ecology, University of Aberdeen
- Commercial Microbiology and Intertek for 11 years
- **ICR. Integrity** (formerly NECE) for 8 years

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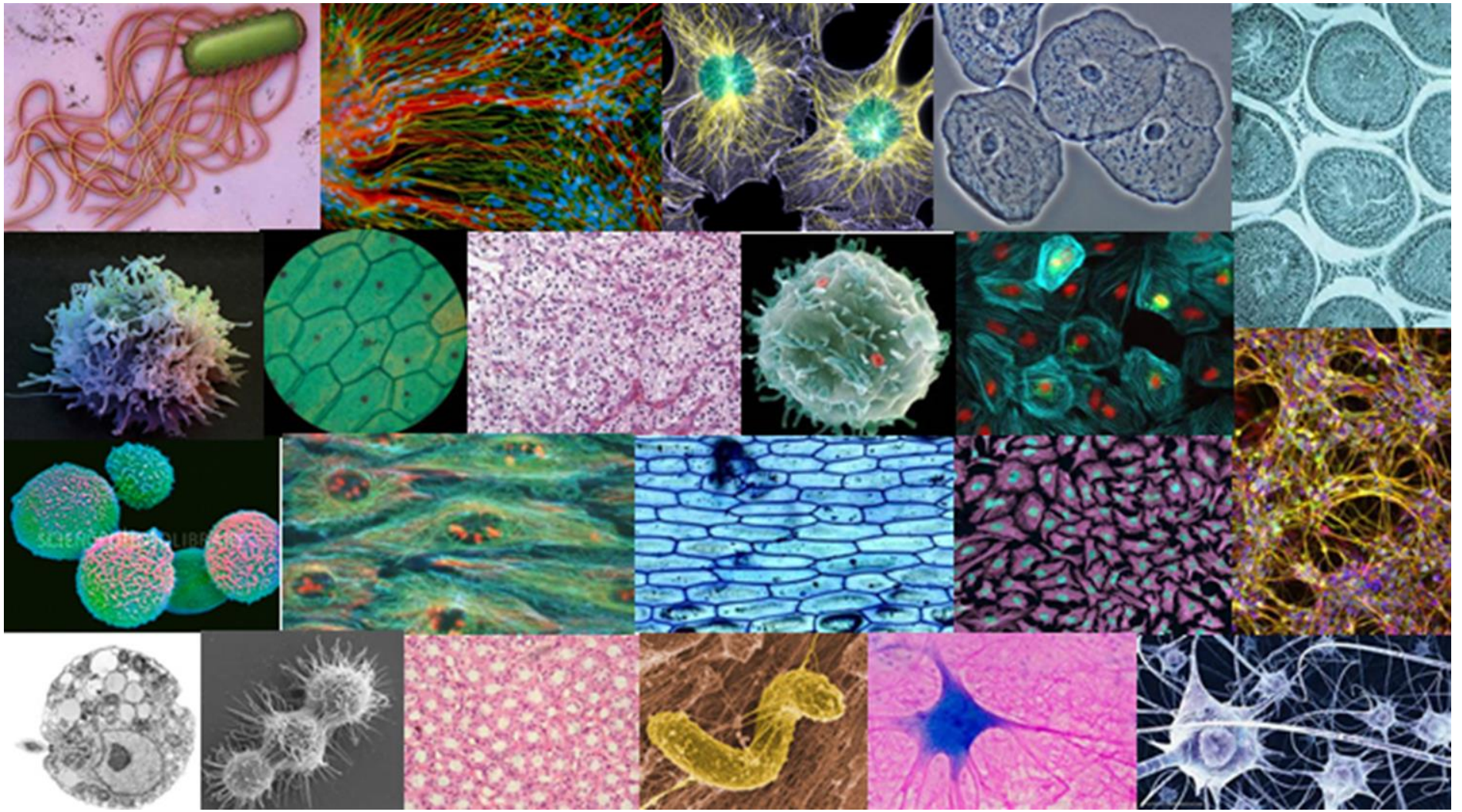


ICR. INTEGRITY AND MAINTENANCE SOLUTIONS

Chemical Injection Solutions

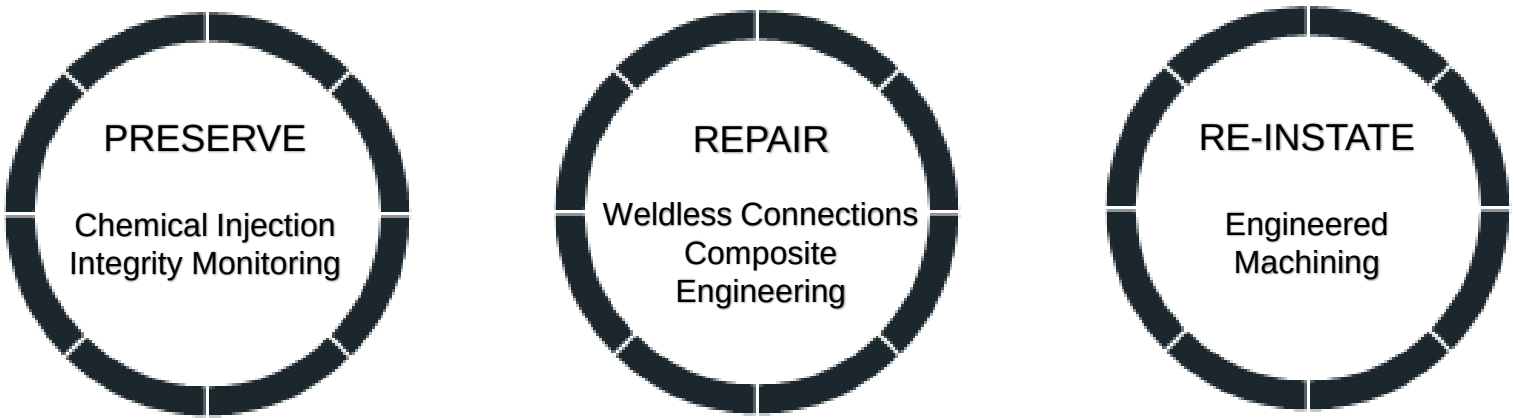
Mechanical Onsite Services

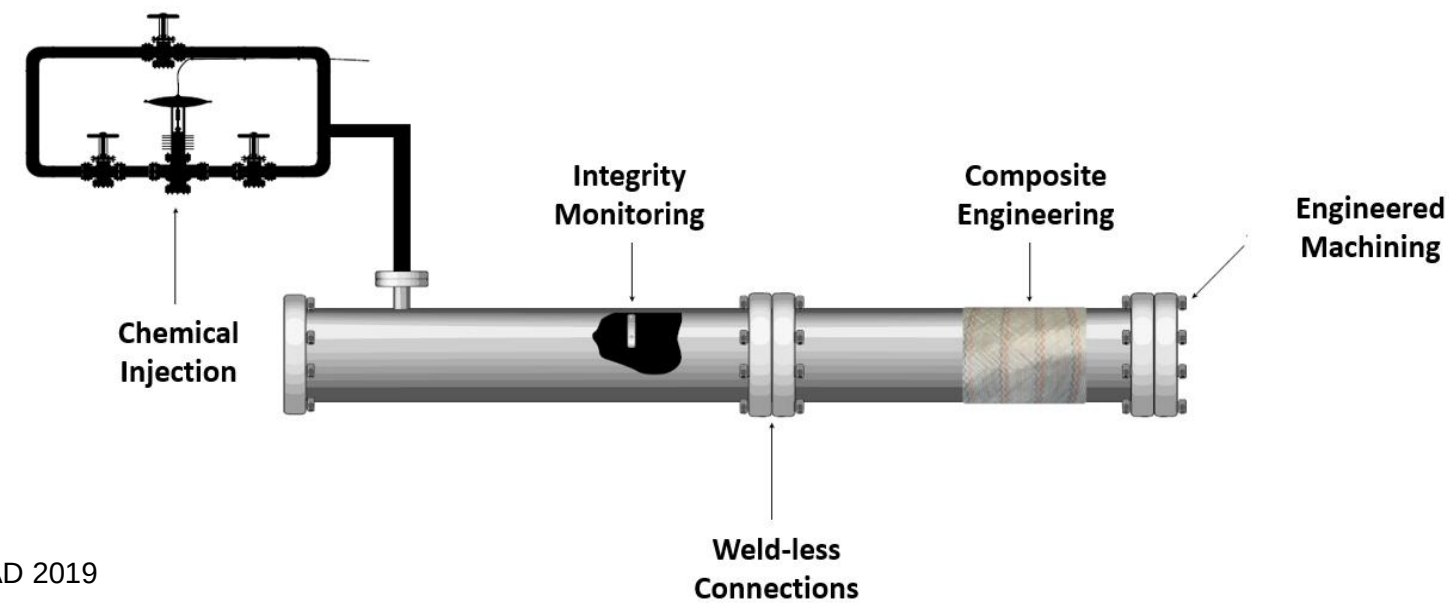
Integrity Monitoring Solutions

Quickflange ™ Weldless Connections

Technowrap ™ Engineered Composites

ICR. PRESERVE, REPAIR & RE-INSTATE





OILFIELD MICROBIOLOGY

- **The aim** of the oilfield microbiologist is to generate useful and appropriate data in order to:

- **Predict** which particular systems, vessels, pipelines, specific locations are under threat from microbiologically influenced corrosion (MIC)

- **Prioritise** areas for treatment according to budget, time and facilities available

- **Monitor** the strategies chosen to mitigate against the effects of MIC

- **Recommend** and monitor strategies to control reservoir souring, plugging and reduced flow

The data generated will feed into the Asset Corrosion Management System

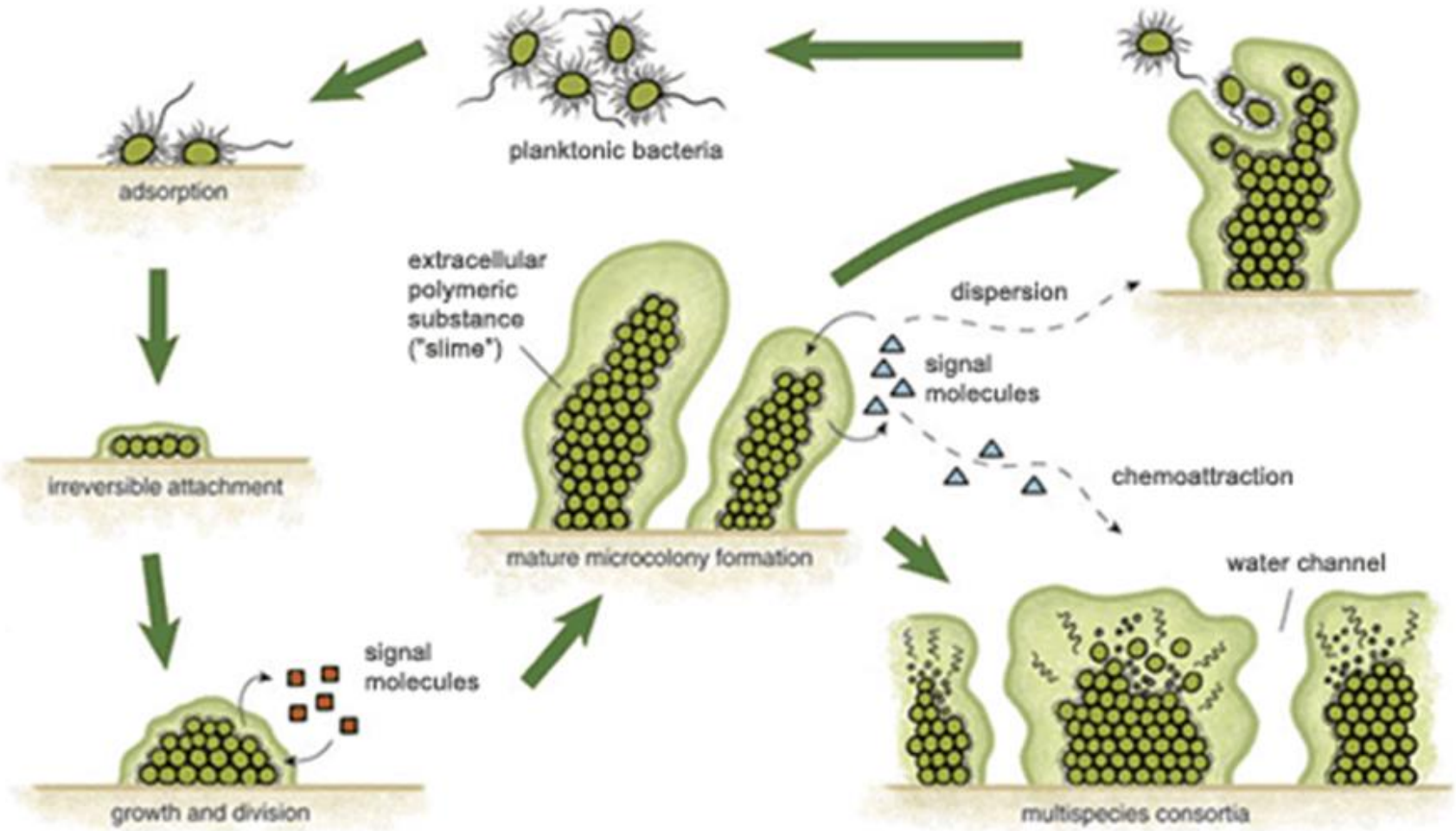
SAMPLES FOR ANALYSIS

Two main types of samples:

Planktonic – crude, produced water, injection water, diesel, cooling and heating media

Sessile – biofilm from coupons, bio-sidestreams and/or other intrusive devices

BIOFILM GROWTH & DISPERSION



LOCALISED (PITTING) CORROSION

CHALLENGES

- **Challenges**
  - **Environment**
  - **Sample Quality**
    - Location
    - Cleanliness
    - Transportation
  - **Analytical Methods/Techniques**
    - Viable counts vs molecular
  - **Nature of the Industry**

ANALYTICAL TECHNIQUES

Choice depends on what you are looking for – and on the budget available!

Three branches of microbes – **archaea**, **bacteria** and **eukaryotes**

MIC is a complex microbial process in which many groups of microbes can be involved:

- sulphate-reducing bacteria (SRB)
- sulphate-reducing archaea (SRA)
- Methanogens (Met)
- acid-producing general heterotrophic bacteria (APB)
- iron utilising bacteria (IUB)
- general heterotrophic bacteria (GHB)
- bacteria and fungi in diesels/gas oil
- (nitrite utilising bacteria) NRB/NUB

ANALYTICAL TECHNIQUES

Techniques: traditional viable counts (MPNs, plate counts)
molecular techniques – ATP, qPCR, FISH, DAPI, NGS

Chemistry: pH, sulphide, bisulphite, Volatile Fatty Acids (VFAs), chlorine residuals, total iron, nitrite, nitrate etc

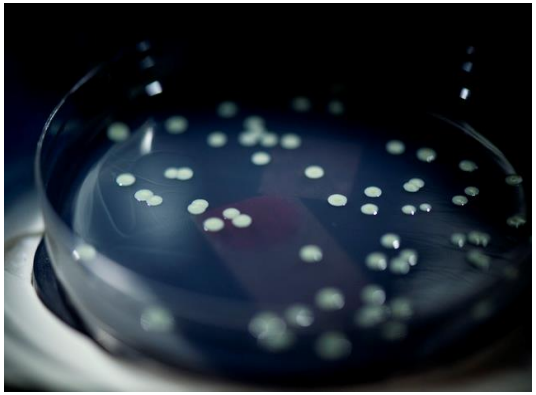
ATP TESTING

- Tests for actively growing cells. Every cell contains ATP
- Several commercial kits on the market (LuminUltra, InstaCheck (Schlumberger), AccuCount (EcoLab), etc)
- ATP (adenosine triphosphate) plus Luciferase = light
- Results are in relative light units which is proportional to the quantity of ATP.
- Can be converted to ME/ml or ME/cm2
- Non specific test originally designed for clean systems

VIABLE CELL COUNTS

Plate counts

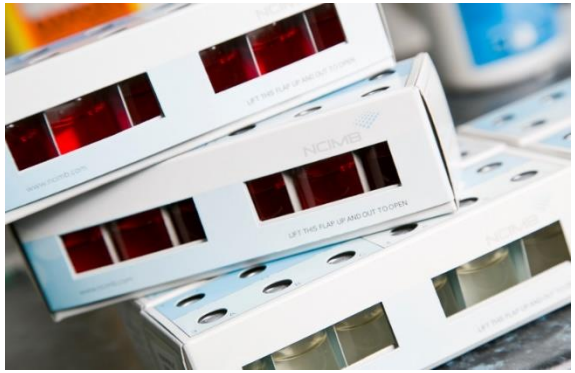
- Can detect a variety of viable microbes
- Difficult to perform in the field/offshore as plates do not travel well
- Need sterile anaerobic chambers to incubate plates for anaerobic bacteria
- Routinely used for diesel/gas oil analysis, potable water monitoring and Legionella counts



VIABLE CELL COUNTS

Triplicate MPNs

- Can detect a variety of active microbes
- Can be performed in field by trained personnel
- Vast body of historic data
- Media must match the conditions of the environment the sample comes from i.e., salinity and pH
- Detects less than 5% of the total community
- Incubation period for SRB is 28 days as per NACE Standard TM0194-2014

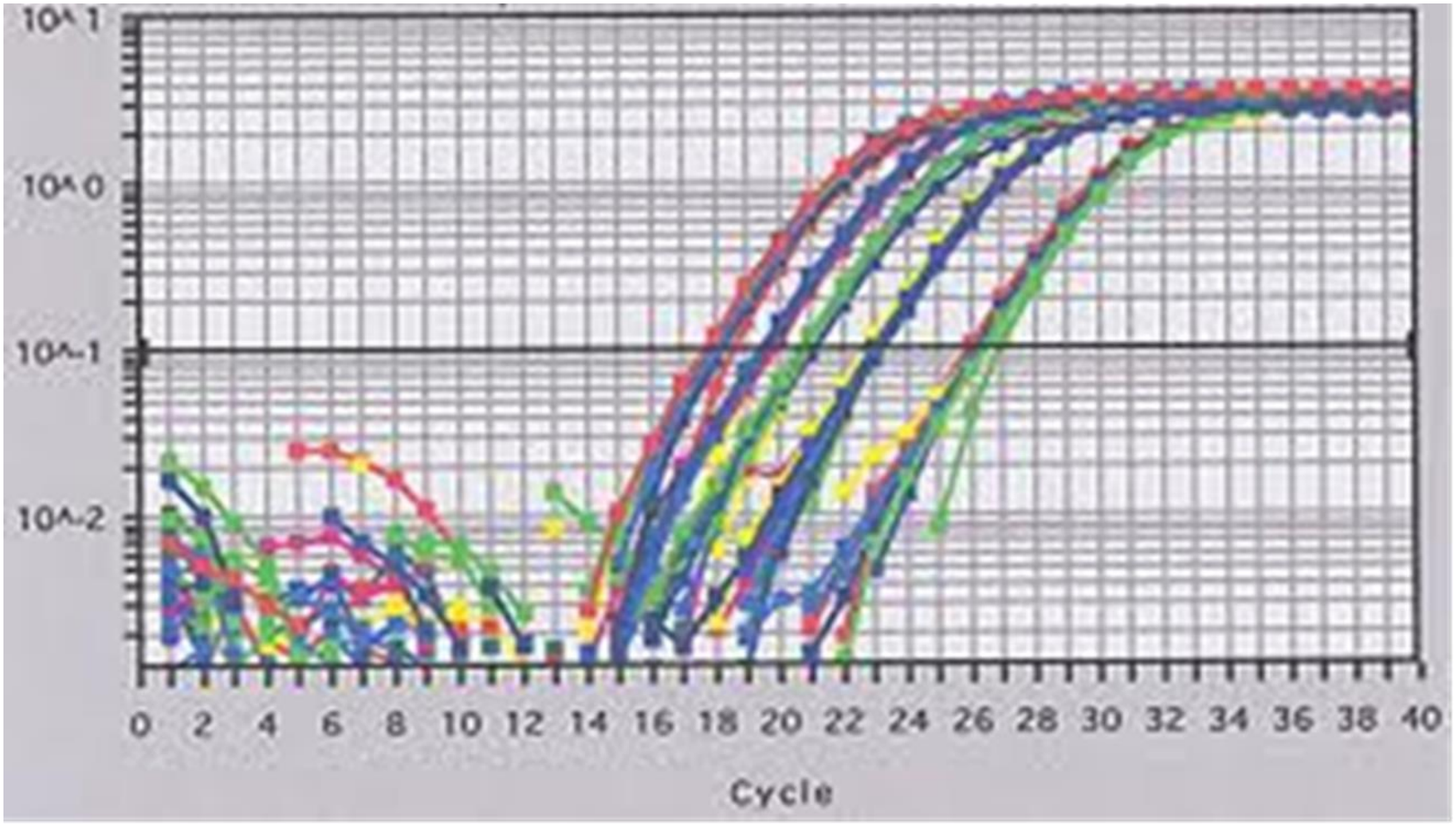


MOLECULAR TECHNIQUES

qPCR (quantitative Polymerase Chain Reaction)

- A laboratory technique based on the polymerase chain reaction
- Used to amplify and simultaneously quantify a targeted DNA molecule
- The cells are lysed and a chemical reaction set up where the DNA is amplified exponentially
- A DNA-binding dye binds to all double-stranded (ds)DNA in the PCR reaction, causing fluorescence of the dye
- An increase in DNA product therefore leads to an increase in fluorescence
- Allows DNA concentrations to be quantified and the number of cells present in the original sample to be estimated.

qPCR - AMPLIFICATION



MOLECULAR TECHNIQUES

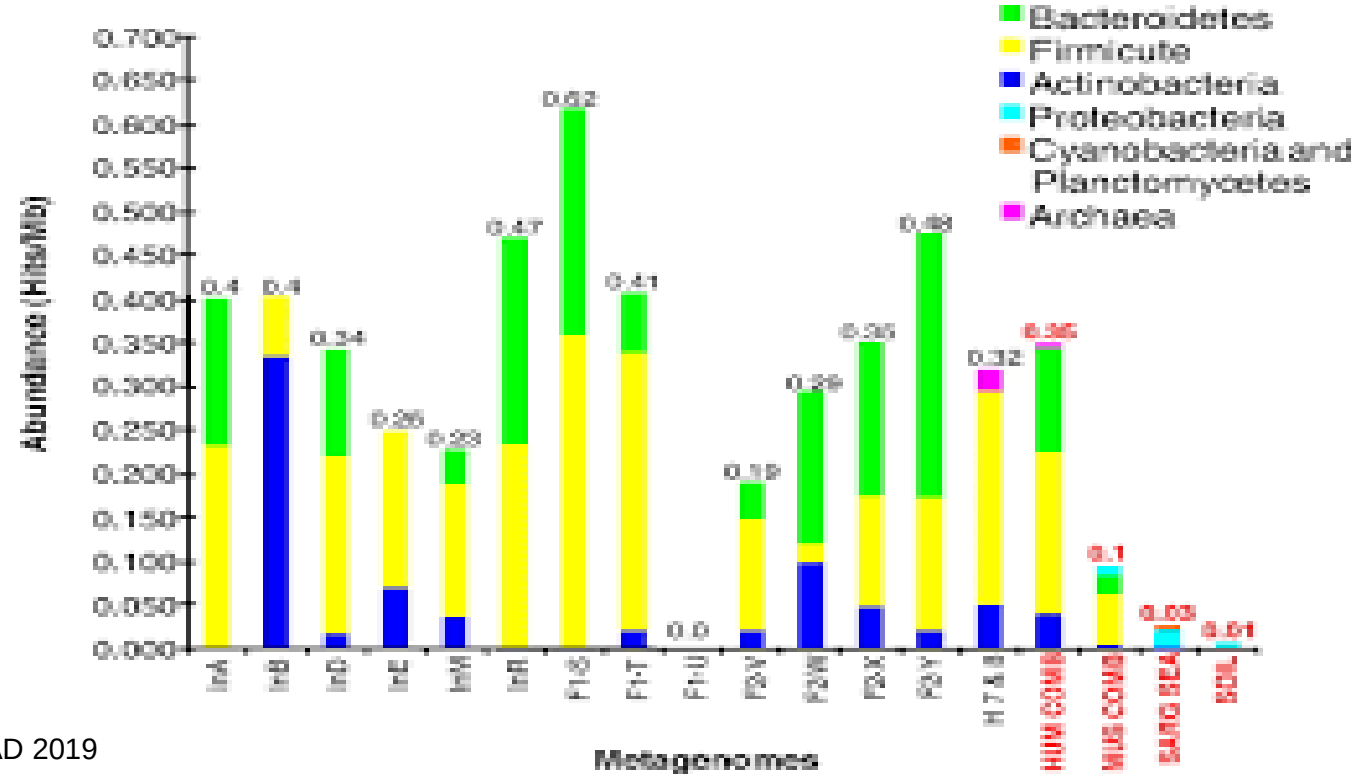
FISH (Fluorescent *In-situ* Hybridisation)

- A laboratory technique based on fluorescent microscopy
- Sample is fixed on site and the fixative must be fresh
- In the lab, a DNA binding dye (DAPI), is added to give a Total Cell Count
- A DNA probe (a short section of nucleic acid labelled with a fluorescent dye) is added and hybridised to the nucleic acid in the target bacteria
- The cells are viewed and counted under a UV microscope

FLUORESCENT IN-SITU HYBRIDISATION (FISH)

METAGENOMICS

- Application of New Generation Sequencing to characterise the total microbial community
- Identifies all micro-organisms present



ADVANTAGES & DISADVANTAGES OF MOLECULAR TECHNIQUES

Advantages (over traditional methods for bacterial enumeration)

- Speed
- Accuracy
- Picks up viable non-culturable cells and archaea
- Can determine which genera and species of bacteria are present
- Relatively easy to take, preserve and ship samples

Disadvantages

- Accuracy
- Cost
- Has to be carried out in the lab
- Samples should be kept chilled during shipping
- Cannot be carried out by offshore chemists (need skilled technicians and expensive equipment)

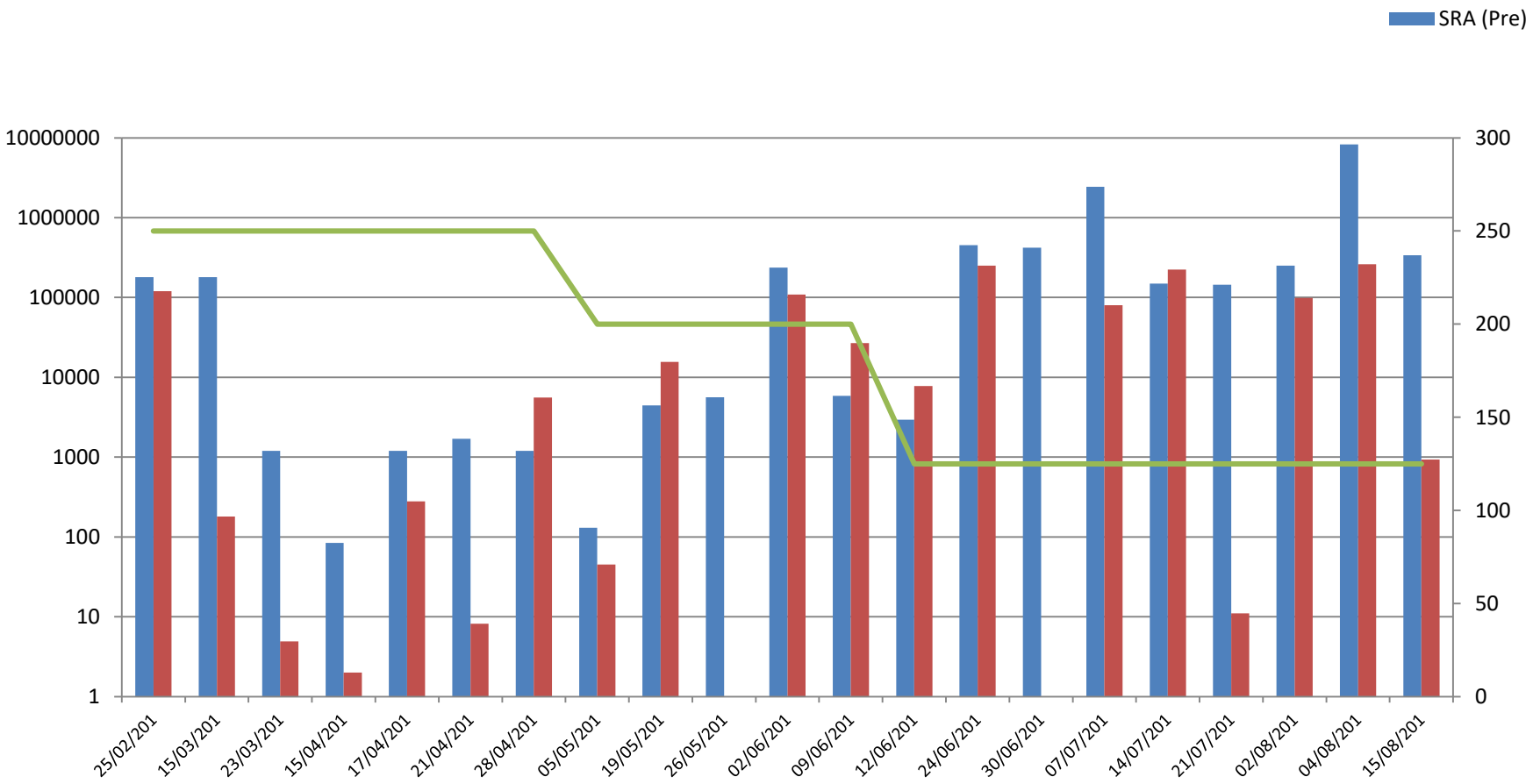
Cell Count ME/ml or cm^2	mGHB MPNs	mSRB MPNs	Total MPN count	qPCR SRB	qPCR SRA	qPCR Total Bacteria
6.2×10^5	2.8×10^1	8.2×10^2	8.5×10^2	5.7×10^6	2.8×10^7	2.4×10^9
1.4×10^3	2.8×10^1	1.0×10^2	1.3×10^2	$<2.1 \times 10^3$	$<2.2 \times 10^2$	4.7×10^5
2.2×10^5	$<3.2 \times 10^0$	4.9×10^3	4.9×10^3	4.9×10^6	4.2×10^7	3.3×10^9
9.0×10^4	1.0×10^2	1.0×10^2	2.0×10^2	1.4×10^6	2.6×10^7	9.0×10^8
3.8×10^5	1.0×10^1	1.0×10^3	1.0×10^3	1.9×10^5	1.5×10^6	2.6×10^8
5.1×10^4	4.2×10^2	2.0×10^3	2.4×10^3	$<2.2 \times 10^2$	$<2.1 \times 10^3$	3.1×10^6
7.3×10^4	$<1.3 \times 10^1$	4.2×10^3	4.2×10^3	$<2.2 \times 10^2$	$<2.1 \times 10^3$	4.1×10^6

DATA TRENDING & INTERROGATION

All data should be graphed/trended on a regular basis – pipelines, drains, water injection, produced water etc.

- Trending of data pre and post biocide applications – especially if it is a longterm project
- Biocide treatments can then be optimised
- Monitoring essential

SRA NUMBERS BY qPCR
PRE & POS BIOCIDE DOSES



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THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?

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Operator's Experience

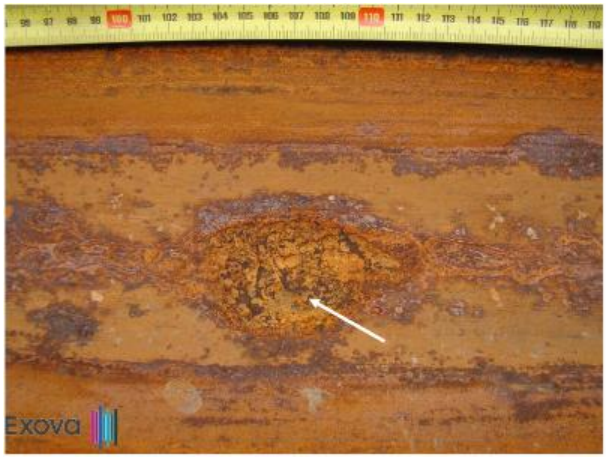
Presented By M Ntim, Materials and Corrosion Engineer, Shell UK

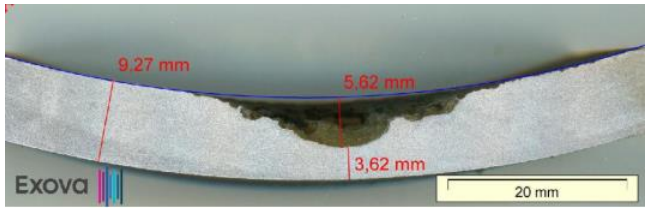



Operator's Experience – Summary

1. MIC has been found in oil pipelines where flowrates are low or stagnant for short periods (batch production).
2. MIC has also been found in water injection pipelines
3. MIC risk is usually detected from topsides bacteria survey and/or pig trash data
4. The mitigation for MIC is to deploy biocide treatment (usually deployed with the pigging frequency if possible).
5. Corrosion rates from prediction models can vary based on flowrates, pigging frequency and effectiveness, and biocide treatment.
6. Corrosion assessment can be conservative
7. Inspection tool limitations – due to the size of pits on pipe surface

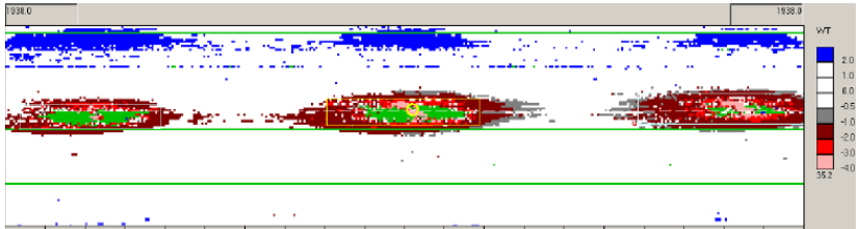
Examples – Oil Pipeline (intermittent service)





Examples – Multiphase oil pipeline

- Carbon steel pipeline – in operation from 1998. The main degradation mechanism expected was CO_2 corrosion.
- In 2007, intelligent pigging was completed (1st inspection) and significant wall loss was reported.
- Review of the pipeline system highlighted the following:
  - Increase of bacteria count in the wash water system – this was required when producing specific wells to ensure corrosion inhibitor effectiveness
  - Metal loss morphology appeared circular in shape
- Pipeline was re-inspected after 5 years. However no change was detected when compared to 2007 data – manufacturing defects or better control?



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Sampling, Analysis and Monitoring of Pipelines for MIC

Laura Tiano
DTI Oil & Gas
Life Science
Danish Technological Institute
Contacts: lti@dti.dk / +45 72 20 10 39

Aberdeen – Icorr Day - 27 august 2019

DTI: WHO ARE WE?

DANISH TECHNOLOGICAL INSTITUTE

- Founded 1906, 1000+ employees
- Leading research and technology company

- Objective: Bridging knowledge with production.

Around 50 employees working with Oil & Gas

- Operations support team
- Offshore field staff
- R&D scientists and engineers

Facilities

- Extensive analysis labs, state-of-the-art equipment
- Dedicated oil field laboratory
- Large-scale coating production facility

Outline

1. Microbial challenges
2. Samples and sampling
3. Analyses
4. Monitoring and system management

Microbially influenced corrosion (MIC)

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- Caused by **presence or activity** (or both) of **microorganisms** adhering to the metal (**biofilms**) and accelerating a-biotic corrosion mechanisms.

- Various metals and some nonmetals are affected (e.g. carbon steel, stainless steel, copper & aluminum alloys)

- Typically seen in the presence of **microbial consortia**, comprising more than one type of microorganism:
  - Sulfate-reducing prokaryotes (SRP)
  - Acid-producing bacteria (APB)
  - Metal oxidizing- and reducing bacteria
  - Methanogens

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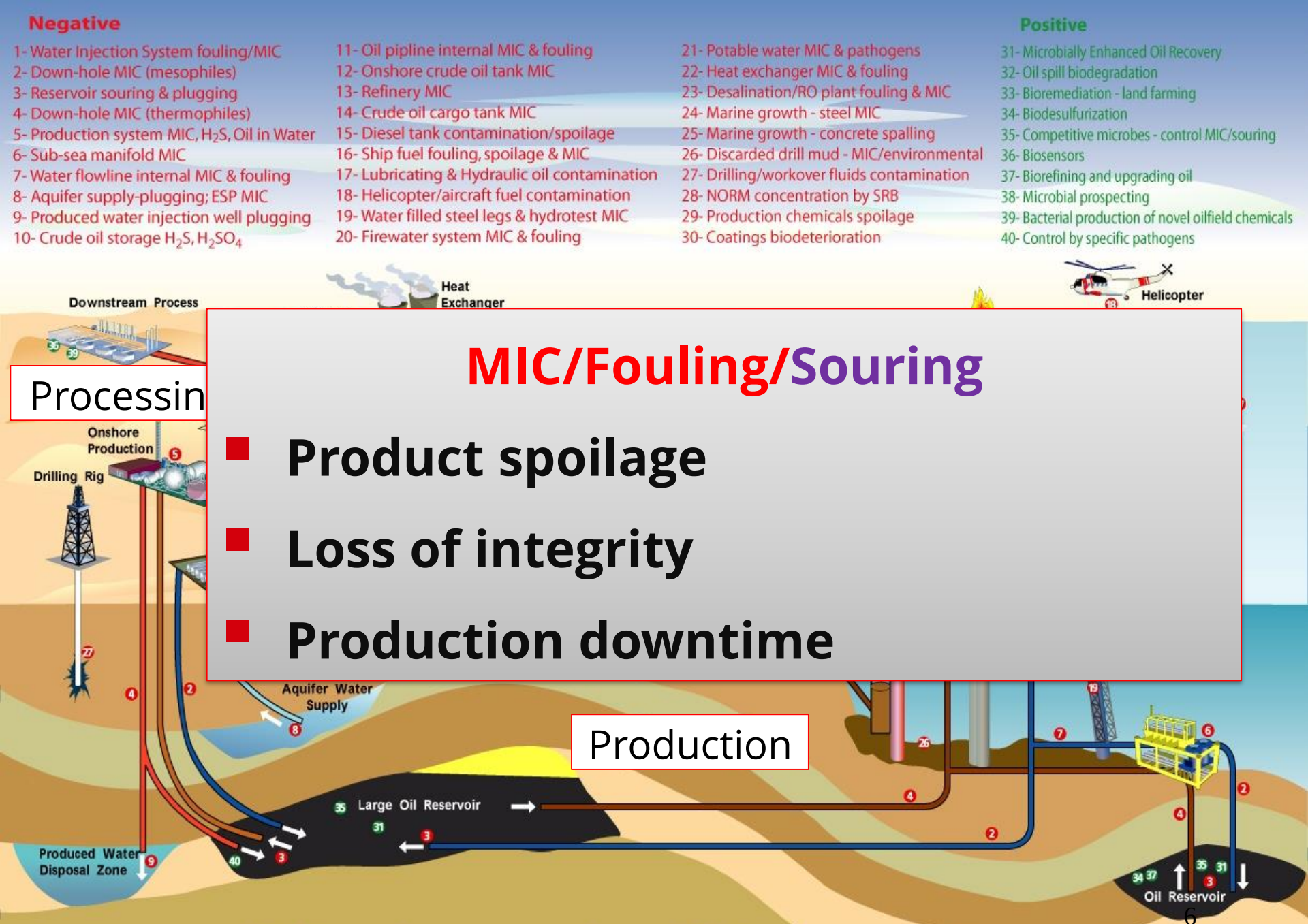
Why do we need to sample?

What is a representative sample?

How do I take the sample and ensure good sample quality?



MIC/Fouling/Souring

- **Product spoilage**
- **Loss of integrity**
- **Production downtime**

Source: Petroleum Microbiology

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Why do we need to sample?

- Routine monitoring
- Quality control
- Suspicion about problems
- Troubleshooting
- Fact finding

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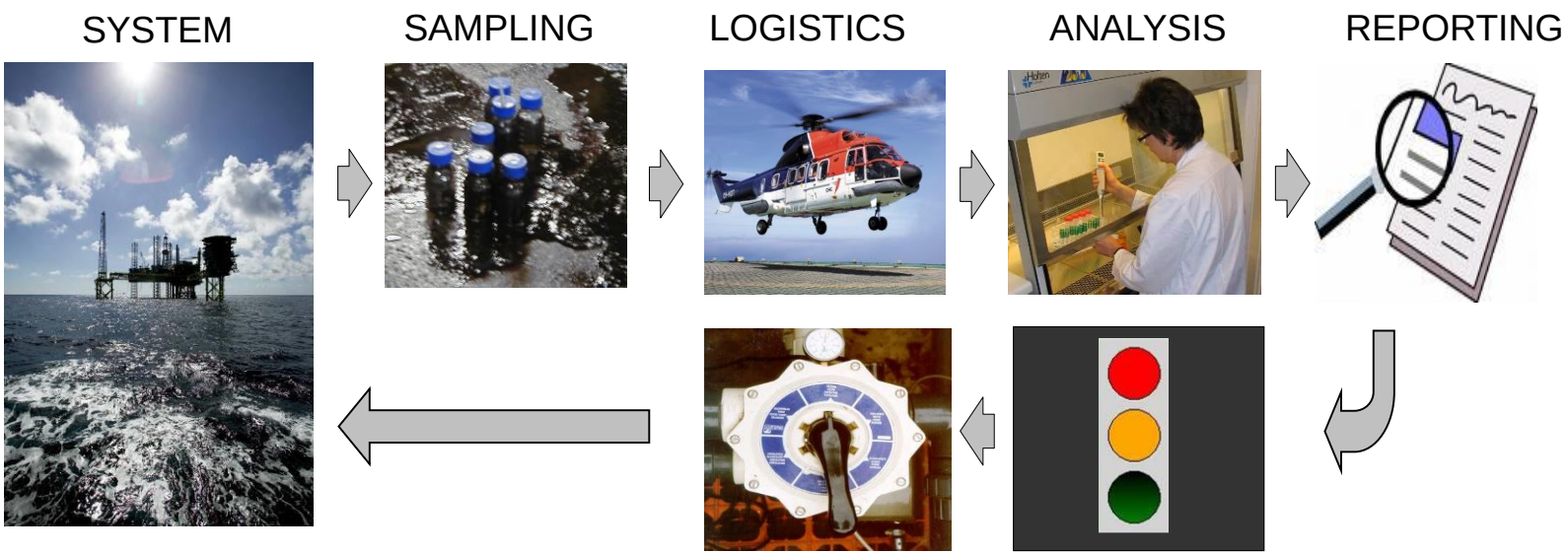
What is a representative sample?

- Sample type
- Sampling point
- Operational conditions
- Microbial hotspots
- Timely analysis

"Sampling is the process of selecting units from a population of interest so that by studying the sample we may fairly generalize our results back to the population from which they were chosen"

From sampling to system management



What to sample: Sample type

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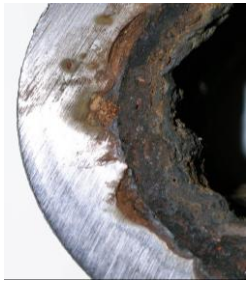
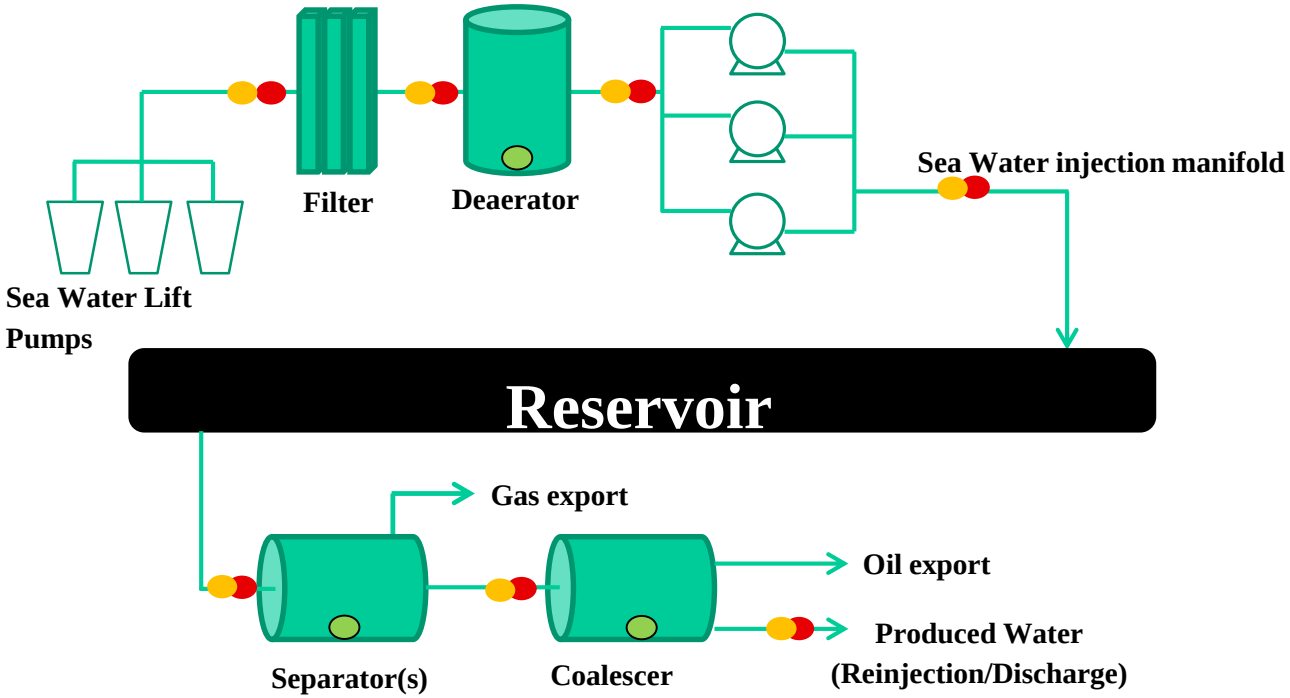
Sample types

- Liquid
  - Water
  - Fuel
  - Crude
- Solid
  - Pigging solids
  - Biofilm
  - Scale
  - Wax
- Gas
- Others
  - Piping
  - Coupons
  - Probes



The advantages of different sample types

Example of offshore injection water system



Water samples

- Easy to collect
- Microbial hotspots ID
- Growth potential
- Trendlines

Solid samples
(biofilm, pigging material)

- Requires good planning: collected only at shutdown periods/ pigging operation
- Verify microbial trends
- Directly linked to MIC risk

Corrosion coupons

- Sampling requires specially trained personnel
- Directly linked to MIC risk
- General corrosion/ corrosion rates

When to sample

- Time and timing
- Stable production?
- Before/after mitigation (i.e. biocide) action?
- Several samples?

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How do I take the sample and ensure good sample quality?

- The right sample equipment
- Thorough sampling procedures
- Ensure the sample does not change over time

The right equipment for the task

- Chemistry:
  - Bottle and preservatives, analysis dependent
  - Glass often required

- Microbiology:
  - **Sterile** plastic
  - Standard kits available (+/-preservative)

- If in doubt about purpose/parameters:
  - 1 L blue-cap flasks covers most needs

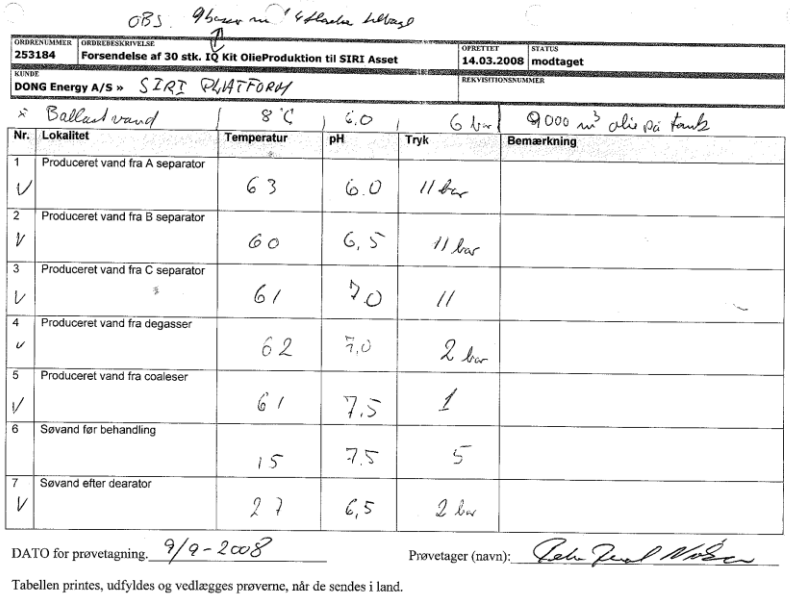
- Different equipment for different sample types

Ensure the sample does not change

- Preservation needed?
- Redox environment
  - *Aerobe/anaerobe?*
- Avoid contamination
  - *Use sterile equipment*
- Temperature
  - *Cool to minimize activity – but do not freeze*
- Time
  - *Minimize transportation (planning and communication)*

Documentation / labeling

- Number / ID
- Exact location / sampling point
- Date / time
- Company / field
- Other relevant information:
  - Visual observations
  - Temperature
  - Pressure
  - Sampler..



OBS. 9 boxes m. 4 flaske tilbage

ORDRENUMMER	ORDREBESKRIVELSE	OPRETTET	STATUS
253184	Forsendelse af 30 stk. IQ Kit OlieProduktion til SIRI Asset	14.03.2008	modtaget

KUNDE: DONG Energy A/S » SIRI PLATFORM

REKVISITIONSNUMMER:

Ballast vand | 8 °C | 6.0 | 6 bar | 9.000 m³ olie på tank

Nr.	Lokalitet	Temperatur	pH	Tryk	Bemærkning
1 ✓	Produceret vand fra A separator	63	6.0	11 bar	
2 ✓	Produceret vand fra B separator	60	6,5	11 bar	
3 ✓	Produceret vand fra C separator	61	7.0	11	
4 ✓	Produceret vand fra degasser	62	7,0	2 bar	
5 ✓	Produceret vand fra coaleser	61	7,5	1	
6	Søvand før behandling	15	7.5	5	
7 ✓	Søvand efter dearator	27	6,5	2 bar	

DATO for prøvetagning: 9/9-2008 Prøvetager (navn):

Tabellen printes, udfyldes og vedlægges prøverne, når de sendes i land.

ID-mærkat/ID-label

Prøvenr./No.:

Sted/Location:

Dato/Date:

Tid/Time:

Firma/Company:

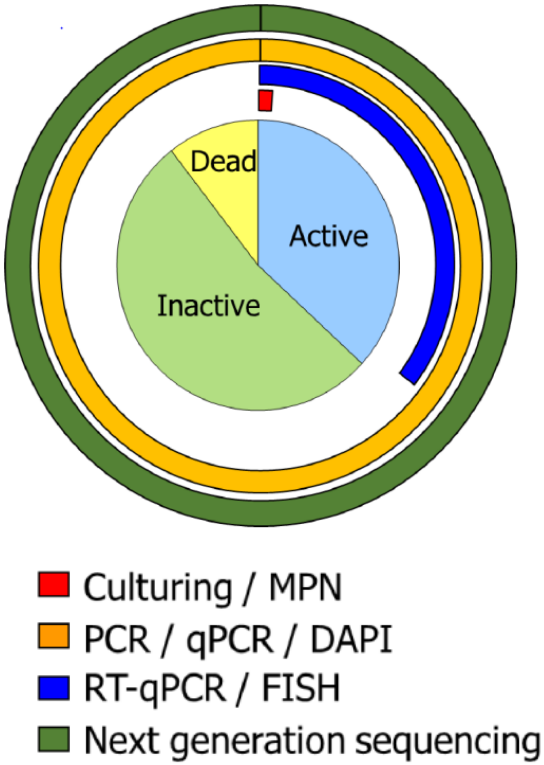
Microbial Analyses

- Culture based (i.e. MPN)
- Microscopy based (i.e. DAPI, FISH)
- Enzyme based (i.e. ATP)

- DNA based, (MMM)

Molecular microbiological methods:

- qPCR
- RT-PCR
- Microbial community analysis (NGS)



Poulsen M. et al., 2016 SPE-183526-MS

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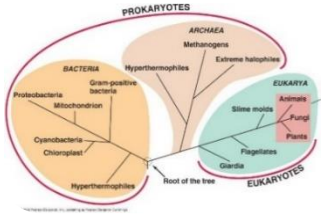
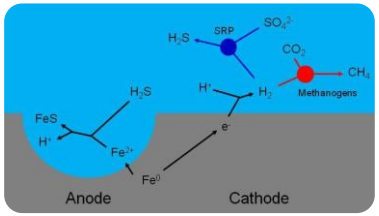
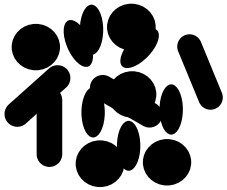
Microbial Molecular Methods



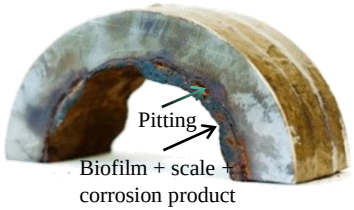
Who is there?



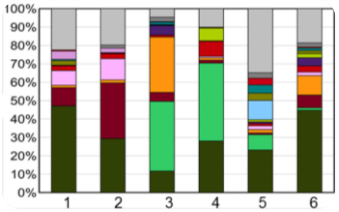
What can they do?



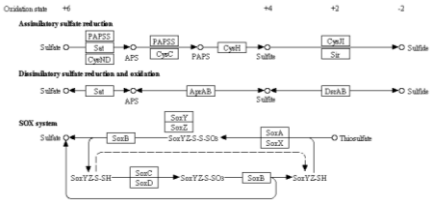
How many are there?



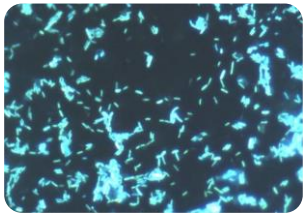
Are they active?



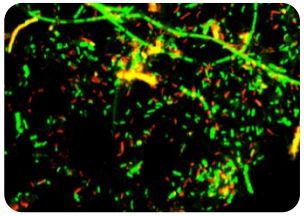
NGS sequencing



Metagenomics



qPCR
DAPI



RT-qPCR
FISH

Water samples

Analysis on water samples:

- Living cells count (DAPI)
- Active cells count (FISH)
- Enzyme based activity

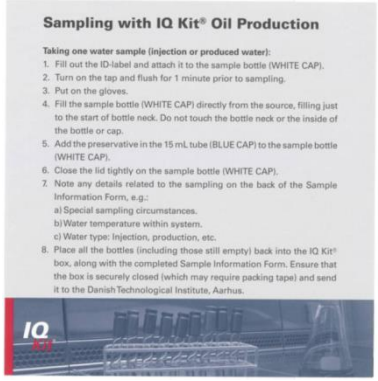
- Total microbial numbers and
  MIC risk indicator groups (qPCR)

- Microbial community composition (NGS)

- Variety of chemical analyses

Sampling procedure: Water samples

- Always safety first!
- Label sample bottles with time, place, name etc.
- Avoid touching and contaminating bottle and inside of lid.
- **Let water run to flush system thoroughly** – think about, what the water should represent?
- Use stabile flow, sloughing of biofilm should be avoided
- The water is anaerobic and should therefore be aerated as little as possible – and no air gap in the top of the bottle!
  - let **overflow** for a couple of volumes (minimized aeration), close.
- Store cold until shortly before transport, keep cool under transport.



Sampling with IQ Kit® Oil Production

Taking one water sample (injection or produced water):

1. Fill out the ID-label and attach it to the sample bottle (WHITE CAP).
2. Turn on the tap and flush for 1 minute prior to sampling.
3. Put on the gloves.
4. Fill the sample bottle (WHITE CAP) directly from the source, filling just to the start of bottle neck. Do not touch the bottle neck or the inside of the bottle or cap.
5. Add the preservative in the 15 mL tube (BLUE CAP) to the sample bottle (WHITE CAP).
6. Close the lid tightly on the sample bottle (WHITE CAP).
7. Note any details related to the sampling on the back of the Sample Information Form, e.g.:
   a) Special sampling circumstances.
   b) Water temperature within system.
   c) Water type: Injection, production, etc.
8. Place all the bottles (including those still empty) back into the IQ Kit® box, along with the completed Sample Information Form. Ensure that the box is securely closed (which may require packing tape) and send it to the Danish Technological Institute, Aarhus.

Solid samples

Analysis on pigging samples:

- Total microbial numbers, MIC risk indicator groups (qPCR)
- Microbial community composition (NGS)

- General Corrosion
- Chemical composition (XRD, XRF, mineralogy, etc.)

Sampling procedure: Solid samples

- Label sample jars with time, place, name etc.
- Put on the sterile gloves
- Carefully scrape off/collect sample material directly from the pig or receiver and put it in the sample container.
- **Fill up the container completely** with sample material; otherwise fill up the container with liquid from the pipeline/receiver to avoid headspace.
- Close the jar carefully.
- After sampling, the samples must be stored cold.

Example:
Water sampling during pig run

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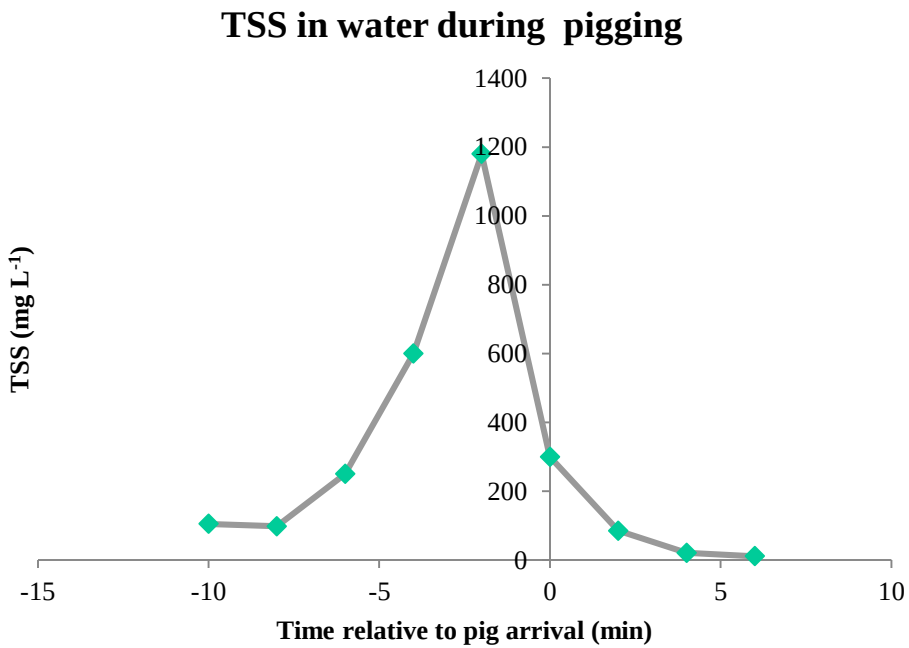
- Require good planning
- Time-consuming sampling

- Use row of 1 L plastic bottles, sample: e.g. every minute
- Label with sampling time
- Sample some time after pig arrival to get water data after pigging
- Pick selection of bottles representing “cloud” for shipping (# can be reduced in lab)
- Store cold (cooling box) until transport and keep cool during transport.

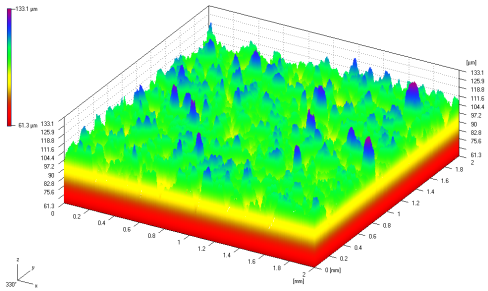


Coupons and Probes

Analysis on coupon samples:

- Total microbial numbers, MIC risk indicator groups (qPCR)
- Microbial community composition (NGS)

- General Corrosion
- Chemical composition
- Pitting and surface scanning
- Weight loss



Sampling procedure: Corrosion coupons

- Label sample jars with time, place, name etc.
- Put on the sterile gloves before handling the coupons.
- Pull the coupon and place it in the sample jar (only one coupon in each sample jar).
- **Fill the sample jar** with sterile saline solution or water representing the system where the coupon was installed *.
- Make sure the jar is completely full - avoid air headspace - then close the jar carefully.
- Fill out the delivery note including all process data relevant to the sampling.
- Store cold until and during transport.

Sampling Offshore: Check list

- ✓ Problem ID - Who to speak to about problems
- ✓ Speed is important
- ✓ Accuracy important
- ✓ Knowledge about oxygen in the samples
- ✓ Difference between Chemistry (dead) and Microbiology (alive) samples
- ✓ Right gear / kits /equipment and procedures
- ✓ Right education in sampling important
- ✓ Solid data will give an optimal solution
- ✓ Everybody in the chain is important – communication!

Example: Pigging samples

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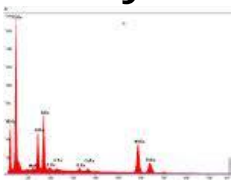
Sample retrieval & trsp.

DNA analysis (MMM)

+

Chemical analysis

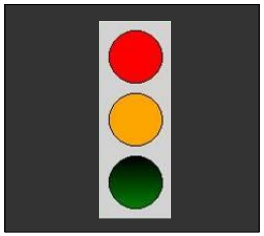


System data:

- Water cut
- Temperature
- Materials/Corrosion
- Water data
- Inspection data

DTI RISK DATABASE

Empirical data from North Sea assets



RISK ASSESMENT

MITIGATION STRATEGY:

- Mechanical cleaning
- Chemicals
- Follow-up & optimization
- Monitoring

From sampling to system management

- ✓ Understand the corrosion threat to the system.
- ✓ Select and applying appropriate prevention and mitigation measures.
- ✓ Monitor conditions to determine whether the control measures are effective, or whether adjustments are required.

PROBLEM SOLUTION / ASSESSMENT
CORRECTIVE ACTION

Setting up a MIC Monitoring Program

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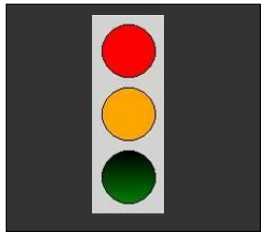
- Injection water systems
- Production systems
- Wells
- Storage tanks
- Pipelines
- …



- ✓ Integrity management and microbial control
- ✓ Better choice of materials for future asset design
- ✓ Improved choice of anti-microbial strategies
- ✓ Optimized pigging and cleaning programs
- ✓ **Reduced OPEX** (maintenance, chemical budgets, downtime)

Setting up a MIC Monitoring Program

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- **Monitoring over a period of time** allows for looking at **trends**.

  Due to normal **statistical variation** associated with sample collection and microbiological testing, more reliable data typically result from performing tests on samples collected over a period of time, rather than from any single sample.

- Microbial monitoring data should be viewed **in combination** with corrosion data.

  Such as from corrosion coupons or in-line inspections, to establish system-specific levels of microbial growth that are acceptable to pipeline integrity.

NACE TM0212-2018-SG Detection Testing and Evaluation of MIC

Example of sampling outline: IW system microbial monitoring

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	Month												
Sample types	1	2	3	4	5	6	7	8	9	10	11	12	**Parameters**
Water samples	X		X		X		X		X		X		Microbiology
Pigging solids			X						X				Microbiology Org/Inorg con. Chemical composition
Coupons			X						X				Microbiology Weigh loss Surface scan

Water – Trends // Hotspot ID // Growth potential in system // Where to focus biocide use

Solids – Can be related directly to MIC Risk // Corrosion and System Integrity

Coupons – Can be related directly to MIC Risk // Pitting // General Corrosion

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Thank you!

www.dti.dk/specialists/oilfield-microbiology/k90453

Laura Tiano
DTI Oil & Gas
Danish Technological Institute
lti@dti.dk

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ICORR ABERDEEN BRANCH WELCOMES

Modelling of Pipeline Susceptibility to MIC

Presented By Steven Loftus, Senior Corrosion Engineer

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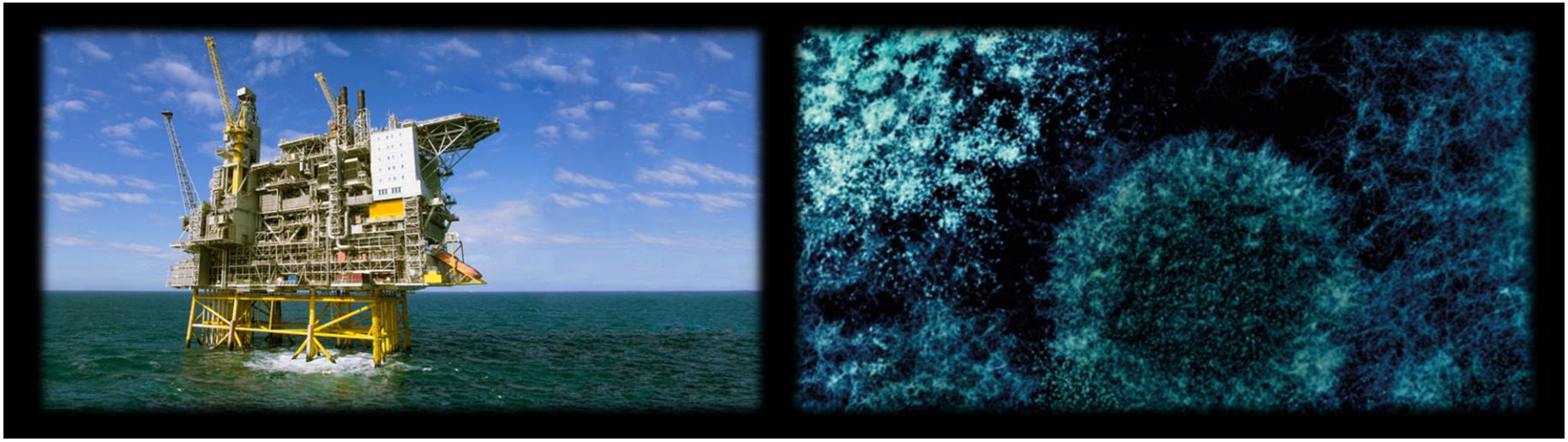

PRESENTATION OVERVIEW

1. Introduction
2. Understanding Pipeline Susceptibility to MIC
3. Modelling MIC in Oil and Gas Industry
4. Proposed MIC Modelling Risk Assessment Procedure
5. Summary
6. Future of MIC Modelling

INTRODUCTION

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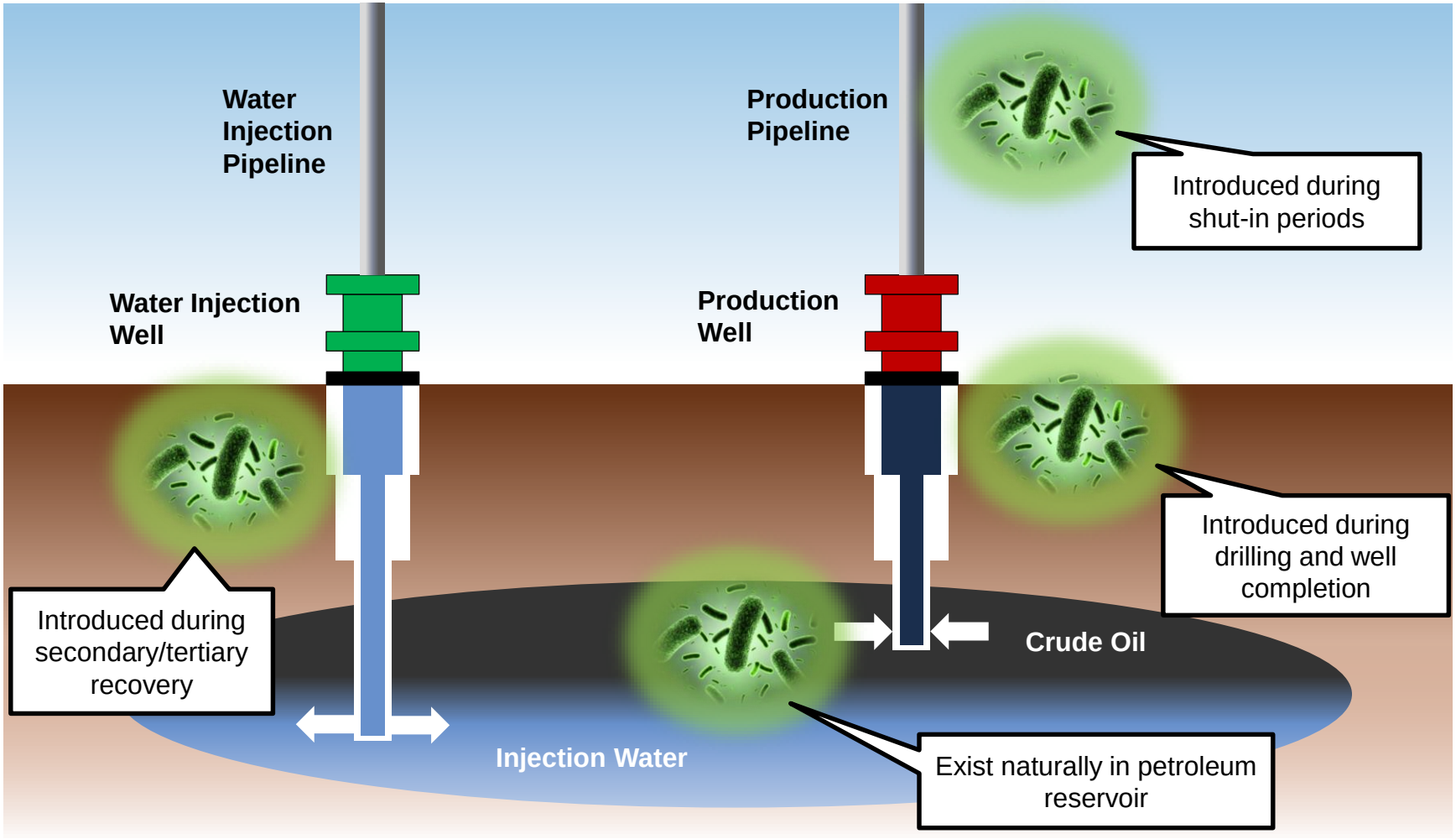
- Pipeline internal corrosion caused by presence of water at metal surface.
- Sediments (‘sludges’) may accumulate in pipelines, comprised of hydrocarbons, sand clays, corrosion by-products, **microorganisms** and water.
- Biologically active pipeline sludges known to accumulate and concentrate water from oil, creating a metal-water interface – leads to formation of localized under-deposit corrosion.
- Sludges can support formation and proliferation of microbial colonies in pipeline systems.

Important initial factor to understand – ***How do microorganisms initially enter pipeline systems?***

INTRODUCTION
COMMON SOURCES OF BACTERIA



INTRODUCTION

Microbiological activity in pipelines can lead to biofilm formation:

- Reduced efficiency of production and equipment operations.
- Favourable environments for anaerobic sulphate-reducing bacteria (SRB), leading to MIC.

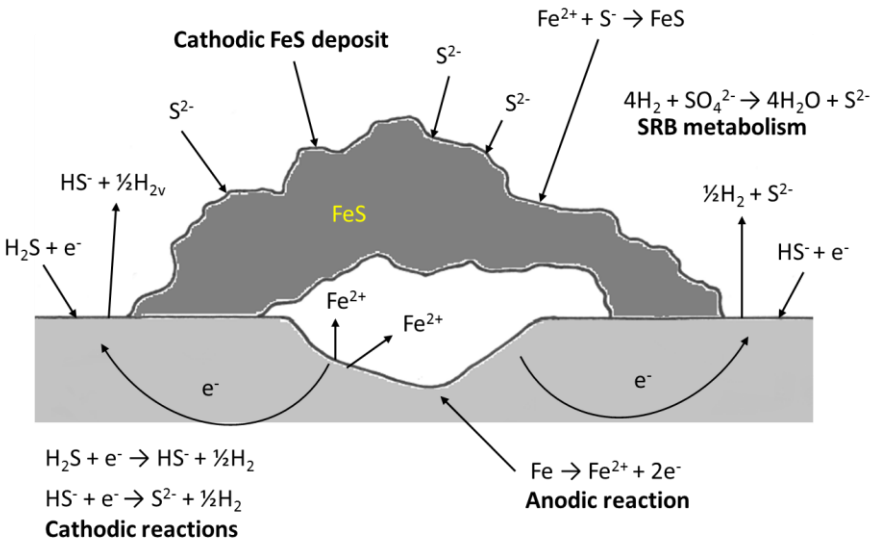
Presence of microorganisms does not necessarily equate to realization and occurrence of MIC:

- Primarily dependent on **pipeline environmental conditions** being viable for biofilm formation and microbial proliferation.
- System must be systematically and routinely monitored for presence of microorganisms.

UNDERSTANDING PIPELINE SUSCEPTIBILITY TO MIC

MIC relatively difficult to predict and diagnose compared to other corrosion mechanisms:

- Complex due to diversity of contributing factors *i.e.* growth of biofilm governed by a number of **physical, chemical** and **biological** processes (**abiotic** and **biotic processes**).



UNDERSTANDING PIPELINE SUSCEPTIBILITY TO MIC

Breadth of disciplines and understanding required in evaluating and predicting MIC.

Two main subject areas:

- **Materials / corrosion science.**
- **Microbiology / environmental sciences.**

UNDERSTANDING PIPELINE SUSCEPTIBILITY TO MIC

Approaches to MIC threat assessment include:

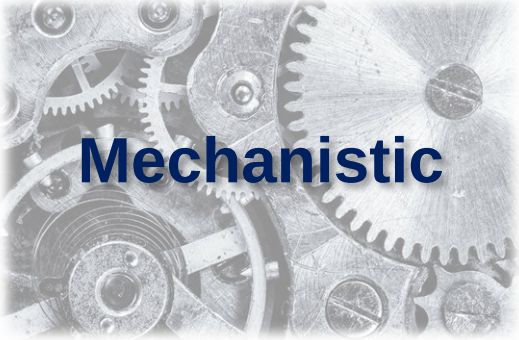
- Analysis of corroded components.
- Chemical and microbiological surveys in conjunction with corrosion monitoring.
- Use of MIC susceptibility and MIC rate-based models.

MODELLING MIC IN OIL AND GAS INDUSTRY
TYPES OF MODELS

Oil and gas industry use models for many purposes:

- Predicting effects of corrosion on asset design and life extension.
- Materials selection (FEED).
- Establishing appropriate mitigation and monitoring programs.
- Optimisation and prioritization of resources.
- Optimisation of risk-based inspection (RBI).

Many MIC models exist in literature, generally classified into three categories:



MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF EMPIRICAL MODELS

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Developed to predict corrosion rates due to MIC based on select measured parameters.

The number of empirical models limited – lack of comprehensive datasets from lab or field testing.

- **Fatah *et al.*** - model that predicts MIC rate for SRB based on abiotic chemistry and linear polarization (LPR) measurements.

- **Grzelak** – statistical analysis of 18 external pipeline defects attributed to MIC:
  - Defects detected by ILI and external pipe environmental conditions collected and evaluated statistically for influence on external MIC.
  - pH and redox potential had highest correlation with MIC rates.
  - SRB concentration – no significant correlation to MIC rate!

MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF MECHANISTIC MODELS

Mechanistic models developed to better relate changes in selected environmental conditions with MIC rates.

- Majority focused on SRB and based on simulating a model biofilm over a corroding metal substrate.
- **Maxwell** - model that predicts MIC occurrence and rate for SRB based on different stages of SRB biofilm formation, as part of risk-based assessment.
- **Gu *et al.*** – model that predicts MIC considering biochemical reactions at the biofilm-metal interface:
  - Charge resistance one of the most important factors during initial biofilm formation.
  - Model + risk-based framework could predict likelihood of biofilm formation in pipelines.

MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF MECHANISTIC MODELS

Area of growing interest – use of data from MMM as input to mechanistic MIC models.

- **Skovhus *et al.*** – qPCR used to study *in situ* microbial consortia and predict MIC.
- Model is divided into two steps:
  - 1st step – estimates processes that occur prior to onset of MIC.
  - 2nd step – calculates corrosion when MIC has occurred.

- Does not include physical or chemical parameters.
- Model implemented in pipeline operations in Danish sector of North Sea by Maersk Oil.

MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF MECHANISTIC MODELS

Some shortcomings with existing mechanistic models:

- Existing models aren't able to predict where and when MIC will occur.
- Majority do not consider biofilm growth characteristics.
- Most rarely account for effects of metabolic products (e.g. H_2S, FeS, *etc.*).
- Few models accurately correlate sessile and planktonic bacteria.
- Some models limit assumed cathodic surface area involved which can significantly affect predicted corrosion rates.
- Most of the models only validated based on short-term lab testing, not with actual field test data.

MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF RISK-BASED MODELS

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Qualitative Approaches

Qualitative assessment of MIC uses collective expertise within a company or from external SMEs hired to take on task.

- SMEs input based on experience and from other analogous / similar situations in the industry.
- Screening assessment to consider all threats and risks – input given in data ranges instead of discrete values and corrosion threats ranked into categories e.g. low, medium or high.
- Advice and guidance limited by existing knowledge.
- Accuracy of results greatly dependent on background and expertise of risk analysts and team members.

MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF RISK-BASED MODELS

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Semi-Quantitative Approaches

Any methodology that has aspects derived from both quantitative and qualitative approaches.

- **Sooknah *et al.*** – MIC susceptibility determined through consideration of pipeline operating conditions that influence microbial growth and biofilm formation. Updated with integration and consideration of MIC-related mitigation measures.
- **Skovhus *et al.*** – combines elements of Sooknah model in a qualitative assessment, both quantitative + qualitative input combined to assess threat of MIC:
  - Considers both Probability of Failure (PoF) and Consequence of Failure (CoF) in defining 'risk'.

MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF RISK-BASED MODELS

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Semi-Quantitative Approaches

- **Skovhus *et al.*** – quantitative + qualitative input combined to assess threat of MIC:
  - 1st stage – PoF screening based on the quantitative and qualitative inputs *e.g.* mitigation efforts, temperature, pH, past failures, *etc.*
  - 2nd stage – if PoF significant, PoF ranked based on quantitative measures alone *e.g.* settlement potential, nutrient availability, mitigation effectiveness, *etc.*
  - Procedure provides a ***MIC susceptibility measure***.
  - PoF ranking essential in calculating risk of system when combined with CoF.
  - CoF typically independent of failure mechanism *i.e.* consequence of leakage by MIC same as consequence of leakage caused by other mechanisms.

MODELLING MIC IN OIL AND GAS INDUSTRY
PROPOSED MIC ASSESSMENT PROCEDURE

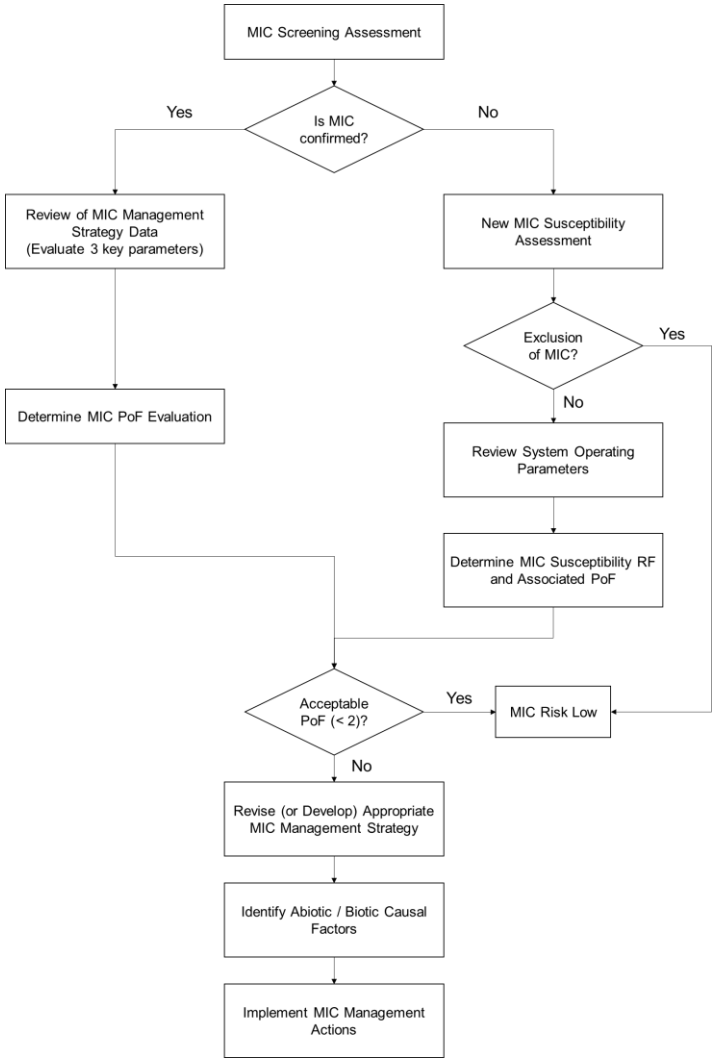
All corrosion models or assessment procedures have some degree of inherent uncertainty:

- No definitive MIC modelling solution to predict MIC in every situation.
- Model predictions should only be used as indicative to plan continuous integrity management monitoring and mitigation measurements.

Suggested ‘best approach’ to model MIC:

- Consider present models.
- Collate best aspects of models ideal and practicable for determining MIC threat, risk and associated PoF for RBI / management.

PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE



PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

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MIC Screening Assessment

Is MIC confirmed?

1. Bacteria detected by routine detection and monitoring methods.
2. Corrosion rate evaluations and bacteria on internal surfaces.
3. Elimination of other active corrosion mechanisms leaving MIC most probable.

MIC PoF Evaluation – 3 key parameters:

1. Corrosion Control Availability (%) (MIC Mitigation Compliance (MMC)).
2. Localised Corrosion Rate (mm/year) (NACE SP0775).
3. Microorganism Enumeration.

PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

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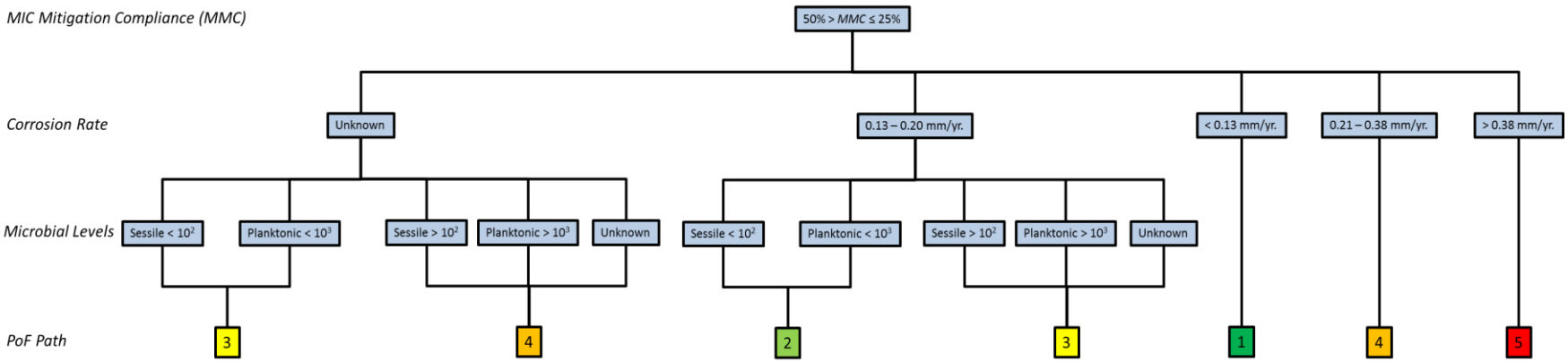
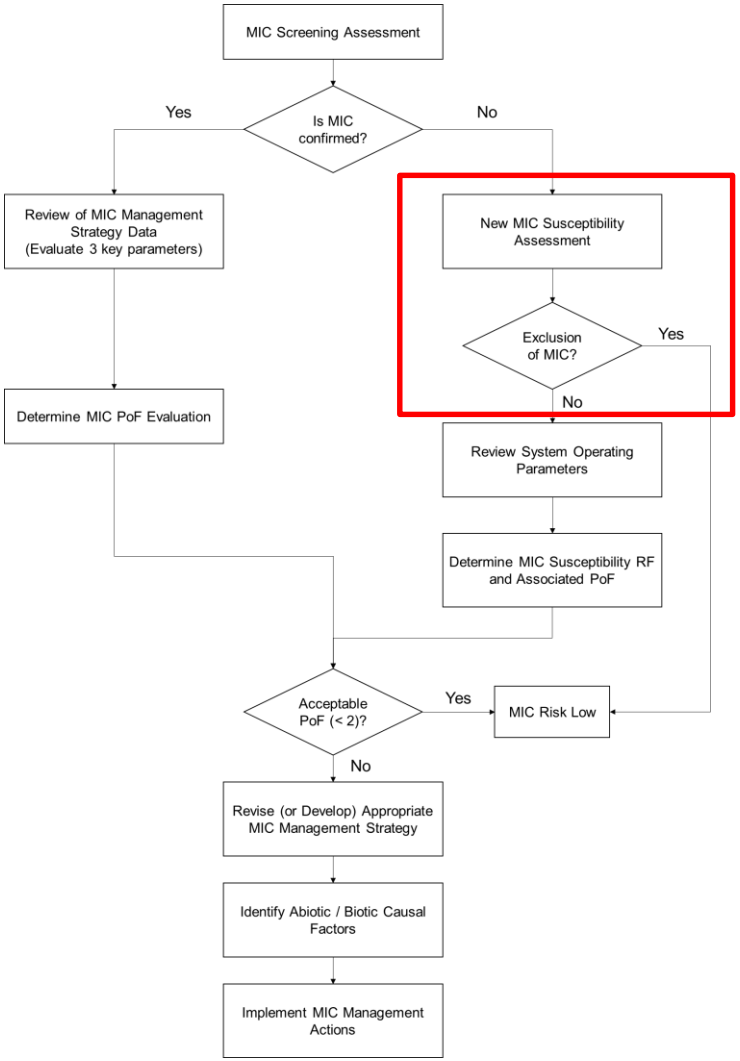
Example MIC Screening Assessment PoF Interaction Diagram



PoF Ranking	1 Very Unlikely	2 Unlikely	3 Possible	4 Likely	5 Very Likely

PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE



PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

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New MIC Susceptibility Assessment

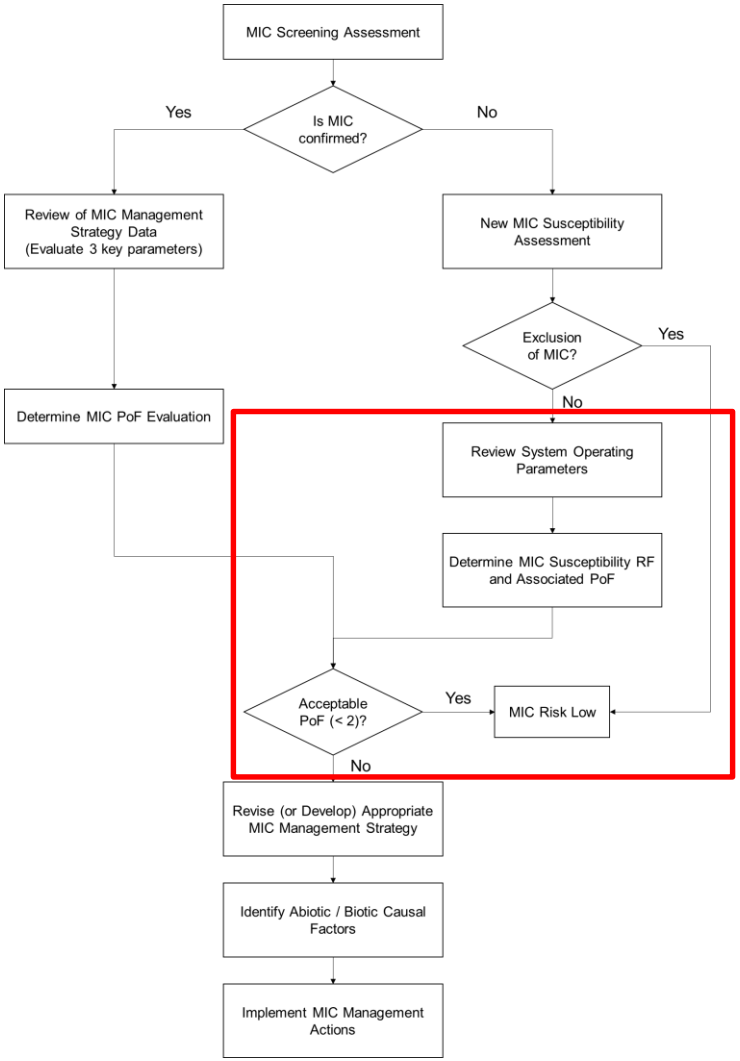
Stage 1: Exclusion of MIC

Biofilm growth can be reasonably excluded if:

- Operating temperature >120˚C.
- Absence of water / moisture.
- Absence or reduced availability of organic / inorganic nutrients.

If any of conditions above satisfied - **MIC Risk Low.**

PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE



PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

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New MIC Susceptibility Assessment

Stage 2: Biofilm Formation, Microbial Adhesion and Growth

Review of system operating parameters – microorganism proliferation greatly influenced by:

- Presence of water.
- Nutritional requirements.
- Oxygen levels, redox potential.
- Temperature.
- pH.
- Salinity.
- Pressure.
- Flow rate.
- Water quality.
- Cleaning frequency.

PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

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New MIC Susceptibility Assessment

Stage 3: MIC Risk Assessment

MIC RF: Sum of all F values divided by total number of contributing operational parameters

Operational Parameter	Parameter Value(s)	Parameter Risk Factor (F)
Flow Velocity	≥3 m/s ≥2<3 m/s >0<2 m/s 0 m/s Unknown	1 2 3 4 5

MIC Susceptibility Index – MIC PoF Ranking Score

0 - 1	1.1 - 2	2.1 - 3	3.1 - 4	4.1 - 5
1 Very Unlikely	2 Unlikely	3 Possible	4 Likely	5 Very Likely

PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

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Corrosion Management Actions

PoF Ranking	MIC Management Action
1 Very Unlikely	• No immediate action required. • Continue with present MIC mitigation, monitoring and inspection. • Current monitoring and inspection frequencies may be reduced with sufficient knowledge of the data trends. • Mitigation activities may also be reduced, but would requires additional monitoring above the present frequency to monitor effectiveness.
2 Unlikely	• As PoF Ranking 1, no additional actions required.
3 Possible	• Identify which abiotic / biotic parameter is leading to a possible MIC threat. If this is not immediate then it may be necessary to conduct a new MIC susceptibility assessment. • Regain control of that parameter through the current MIC control strategy, through increasing the current mitigation element along with more frequent monitoring and inspection to determine if control has be regained. • If control is not regained over a 6 to 12 month period using current mitigation practices then the PoF ranking shall be elevated to PoF 4 and associated actions undertaken.
4 Likely **AND**	• Conduct a new MIC detailed assessment to determine which abiotic / biotic parameters of the system are causing an elevated risk of MIC. • Review operational history to determine if there has been any change to the system parameters that has led to a high-risk evaluation. • Conduct a review of the present MIC strategy to determine why it is not being effective. • The present biocide used with respect to both planktonic kill efficacy and biofilm penetration efficacy is potentially limited and selection of a new biocide or increased dose regime may be required. • Continuous injection of the same biocide has led to microorganism phenomic adaptation resulting in a strain that now has resistance to the biocide. At best the biocide is resulting in injury rather than kill. Utilisation and frequent variation of at least two blends of specific microbially-targeted biocides is required. Dose and frequency will be established through consultation with the chemical manufacturers based on laboratory and field testing. *Note; Ensure suitable biocide testing protocols are followed with specific consideration to; bacterial kill, biofilm penetration, regrowth, contact time and dosage.* • Pipeline cleaning frequency may be insufficient, if so consider increasing the frequency and conduct additional microbial monitoring to determine if the additional control has been effective. • The type of cleaning (cleaning pig) utilised may not be efficient. Try an alternative (more aggressive) cleaning pig type more suitable to the removal and disruption of stubborn biofilms. • With any mitigation change it will be necessary to conduct further corrosion and microbial monitoring to determine the effectiveness of the new strategy. • If corrosion rates are unknown then the installation of appropriately located corrosion coupons, probes, bio-studs should be considered. • Alternatively monitor corrosion rates through direct assessment at appropriate locations which have been determined to be high-risk locations for MIC.
5 Very Likely	

SUMMARY OF PROPOSED PROCEDURE

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- MIC Risk Assessment Procedure:
  - MIC Screening Assessment and PoF Evaluation for systems with **confirmed MIC**.
  - New MIC Susceptibility Assessment for systems where **MIC is unconfirmed**.
- Based on recently developed strategies for assessment of MIC – elements of Skovhus approach to determine PoF of MIC.
- Assess key abiotic and biotic parameters to establish potential for biofilm formation and microbial proliferation.
- Appropriate MIC management actions can be implemented based on evaluated PoF score.

FUTURE OF MIC MODELLING IN OIL AND GAS
INDUSTRY NEEDS

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- Current MIC models are principally susceptibility ranking models or mechanistic rate-based models focused on a specific microbiological activity.
- Industry need – move from reactive to proactive MIC management:
  - Improved prediction models considering both biotic and abiotic corrosion mechanisms.
  - Corrosion rate models.
  - Risk models that can integrate large datasets accumulated for assets over operating life - intelligent input to risk and RBI models.
  - Data from MMM should be incorporated and used in meaningful way – provides greater resolution of microbiome present.
    - MMM data + inspection data (*e.g.* ILI) to improve prediction methodologies.
  - Models that can ‘learn’ from past occurrences / failures of MIC.

THANK YOU FOR JOINING THIS PRESENTATION.

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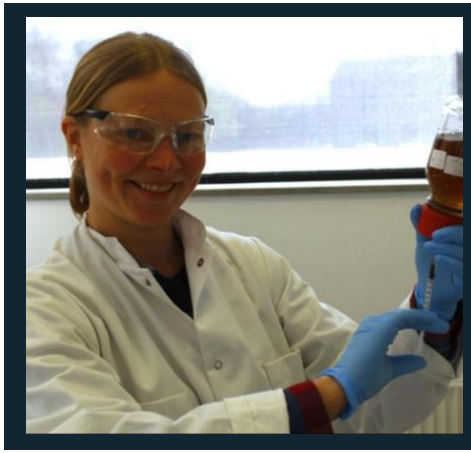
Chemical management of Pipeline MIC: strategies for improved mitigation

Lone Tang, Senior specialist DTI

Aberdeen iCorr Day 27 august 2019




Mitigation of MIC

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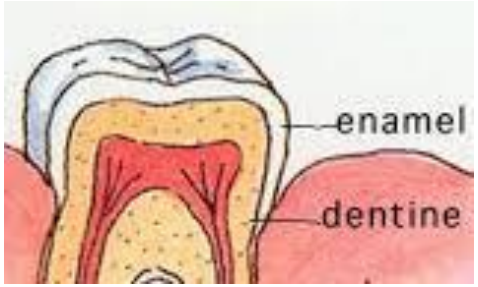
MIC mitigation is about the control of biofilms!



Protective coating

Mechanical cleaning

Chemical cleaning

Mitigation of MIC

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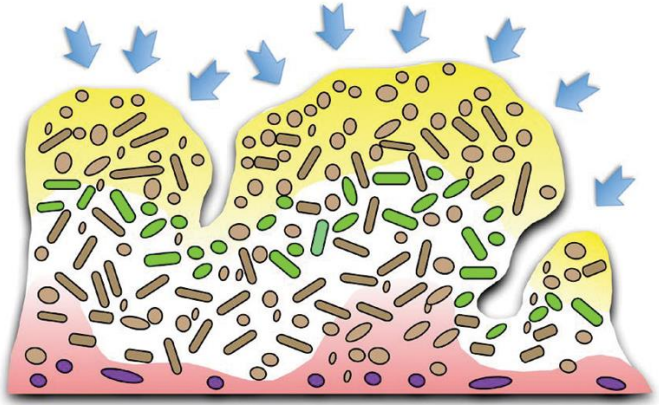
- The biofilm challenge - high biocide dosages are required!

- Biofilm defense mechanisms
  - The biofilm matrix act as a diffusion barrier (Mah and O'Tool 2001)
  - Low growth rate slow down biocide uptake
  - Changes in gene expression (e.g. production of enzymes that degrade biocides or production of effluent pumps)
  - Synergistic interactions between microbial groups



Biocide selection – the ideal biocide

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Compatible

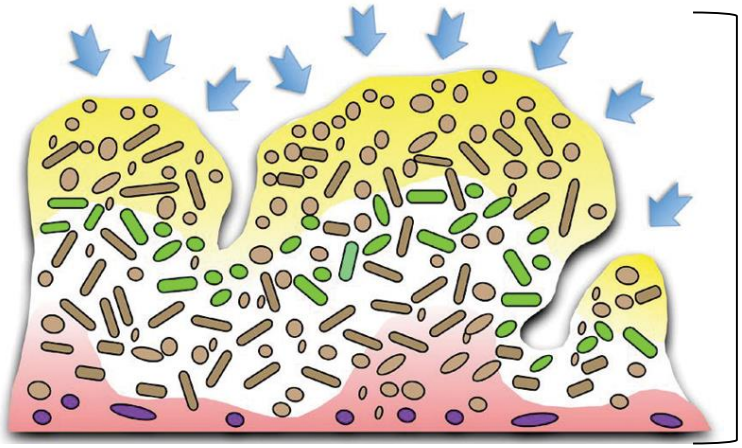
- Compatible with system
- Non-corrosive

Handling

- Non-toxic/non-hazardous
- Degradable
- Easy transport
- Long shelf life
- Cheap

Effective

- Targeting the right organisms
- Fast biofilm penetration
- Rapid effect
- No microbial resistance
- Active in low concentrations



Biocides in the oil & gas industry

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The past

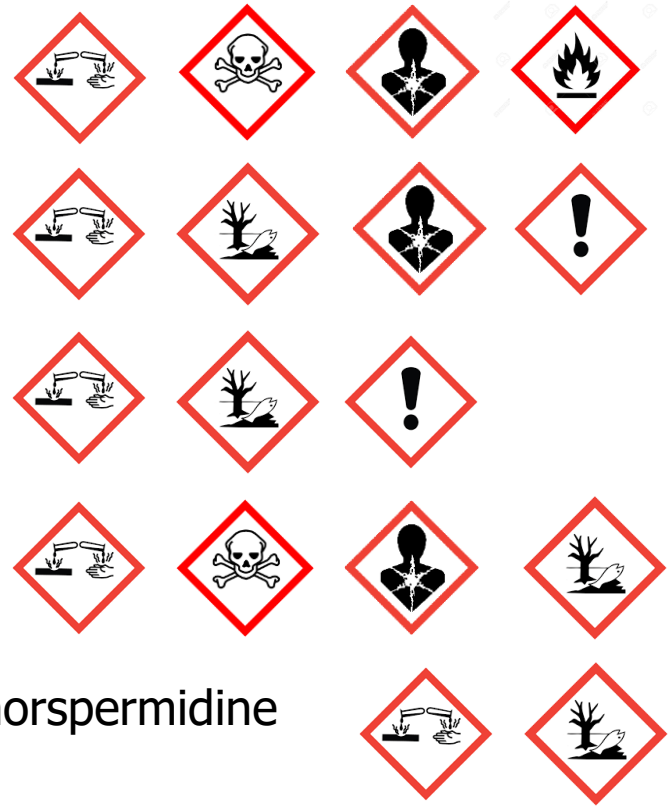
- Formaldehyde
- Glutaraldehyde

The present

- Quarternary ammonium compounds
- Quarternary phosphonium compounds
- Chloride

The future

- ”Green” solvents e.g. ionic liquids
- Enhancers e.g. EDDA, d-amino acids, norspermidine
- Bacterio-phages?
- Quorum sensing inhibitors?



Biocide overview - aldehydes

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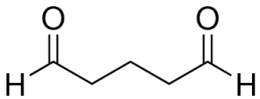
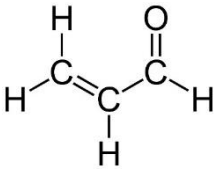
Glutaraldehyde



- Good system compatibility (except e.g. primary amines, ammonia)

Acrolein (2-propenal)



- Dissolves FeS
- Soluble in oil
- Biofilm effect only documented by field studies (Penkala *et al.* 2004)

Common features

- Effective antimicrobial agents; cross-link proteins → inactivate cell membrane, and cross-link DNA
- Can be applied in liquids with high organic content
- Scavenge H_2S and react with R-SH (i.e. bad compatibility with oxygen scavengers)
- Risk of microbial resistance
- Biodegradable

Biocide overview – phosphonium compounds

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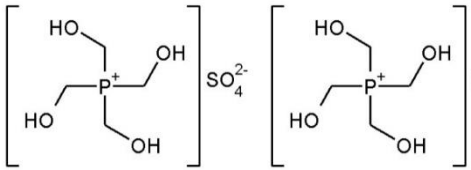
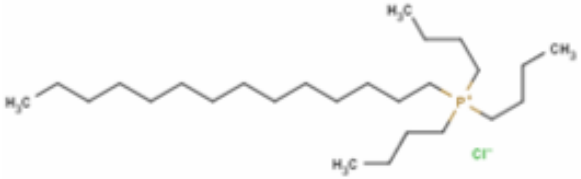
THPS (Tetrakis hydroxymethyl phosphonium sulfate)



- Quaternary phosphonium compound
- Releases formaldehyde with increased pH
- Proven antimicrobial properties
- Limited effect on biofilms (Sharma *et al*. 2018)
- Compatibility issues with anionic friction reducers, chlorine and oxygen scavengers

TTPC (Tributyl tetradecyl phosphonium chloride)



- Surfactant!
- Potential foaming and formation compatibility issues
- Effective towards planktonic SRB (Kramer *et al.* 2006, 2008, Wenthworth *et al.* 2018)
- Biofilm inhibition and dispersion properties (Kim & Park ,2015)
- No reactions with chlorine (Wenthworth *et al.* 2018)
- Unknown* compatibility with anionic scale and corrosion inhibitors

* Some vendors list it as TTPC as having compatibility issues, while other list is as beeing compatible

Biocide overview - surfactants

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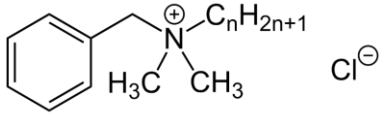
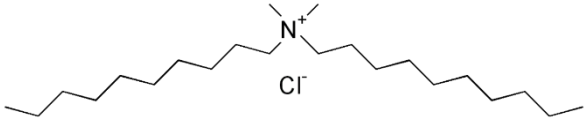
Benzalkonium chloride (BAC) / alkyl dimethyl benzyl ammonium chloride (ADBAC)



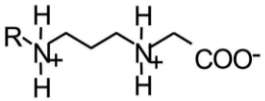
- Risk of bacterial resistance (e.g. Grobe 2002)
- May influence permeability of reservoirs

Didecyl dimethyl ammonium chloride (DDAC)



- Lower foaming, higher tolerance to protein loads and hard water, better kill effect (source chemical vendor)

Some amines e.g. Cocodiamine (1-alkyl (C6-C18)-1,3 propane diamine acetate)



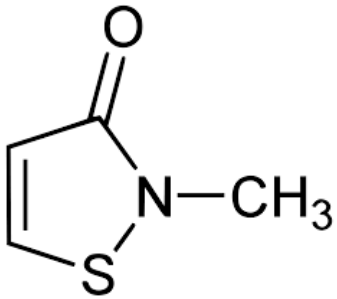
Common features

- Effective at low dosages
- Disrupts cell membrane, destroy proteins, inactivate enzymes
- May improve uptake of other biocides
- Decreased effect with high salinity and mineral content (formations)
- Significant foaming potential and risk of oil emulsions
- Compatibility issues with anionic additives and oxidizing agents

Biocide overview – Isothiazolones

Isothiazolones e.g. MIT (Methylisothiazolinone)

- React with amino acids and inhibit metabolism (4-6h for kill, minutes for inhibition of metabolism) (Williams 2004)
- Incompatible some corrosion inhibitors, oxygen scavengers
- Inactivated by e.g. amines and **sulfides**, pH >7



Biocide overview – Organobromides

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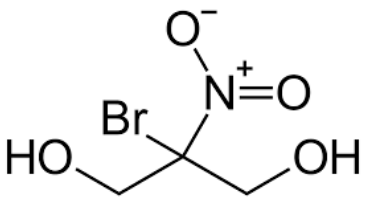
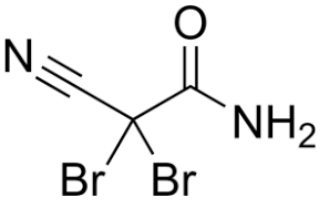
Bronopol (2-bromo-2-nitro-1,3-propanediol)



- Slow kill efficiency, but longer lasting
- Effective towards biofilm at 250 mg/l (Messi *et al*. 2017)

DBNPA (2,2-dibromo-3-nitrilopropionamide)



- Very fast killer, but degrades quickly
- Can prevent biofilm formation when dosed continuosly, but cannot remove biofilm, and resistant subpopulation in biofilms observed (Siddiqui *et al*. 2017)

Common:

- Not recommended for sour systems
- Not recommended for high pH
- Not recommended for >50 ^{0}C

Biocide overview – oxidizing biocides

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e.g. Chlorination, Chlorine dioxide, Hydrogen peroxide, and ozone

Common features

- Attack and oxidize the microbial cell wall, membranes, cell material and DNA
- Relatively efficient towards biofilm
- The disinfection effect depends on concentration and contact time
- Effective for clean water systems such as injection water

- No effect after initial kill
- Poorly effect in liquids with high organic content.
- Not suitable in areas with explosive atmosphere (ATEX)
- Compounds are corrosive
- The oxidizers will react will other chemicals applied

Biocide overview – future chemicals

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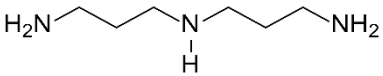
Polyamines e.g. Norspermidine

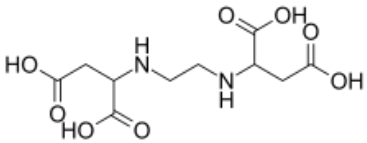


- Interact directly with sugar-based molecules that hold biofilm together (Kolodkin-Gal *et al.* 2012)
- Can disassemble biofilm, but the dispersive and inhibitory activity on biofilms dependent on biofilm species (Ramón-Peréz *et al.* 2015, Si *et al.* 2014, Cardile *et al.* 2017)
- Limited knowledge of compatibility, but contains amine (i.e. not compatible with e.g. glutaraldehyde and chlorine)

D-amino acids

- Disperse some biofilms but not all
- Improved effect of ADBAC and THPS against oil field biofilm (Jia *et al.* 2017)

Chelators e.g. EDDS



- Proven antimicrobial effect
- Non-toxic biodegradeable
- Compatibility issues as it react with ions and thereby loose effect

Ionic liquid

- Many ionic liquids has antimicrobial properties (e.g. DDAC)

Biocide validation process

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- How to indentify the best chemicals for MIC mitigation for your system?
- Challenges:
  - Compatibility: system water composition, other chemicals, materials
  - Efficacy and required dosages depend on liquid composition and microbial species present
  - Biofilms will regrow due to the continuous flow of water
  - Repeated treatments with a biocide may promote growth of microorganisms more resistant to this biocide

Biocide validation process

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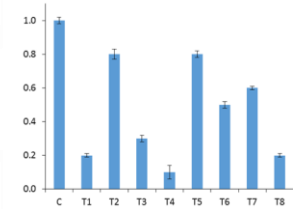
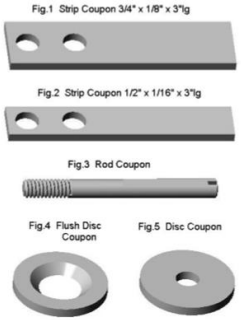
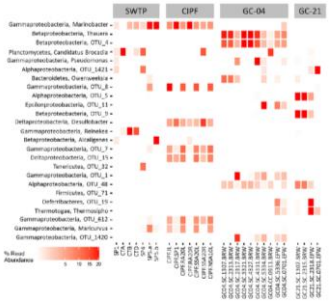


Field Implementation

System Sampling





Risk Evaluation

Lab Biocide Optimization

Testing biocide efficiency

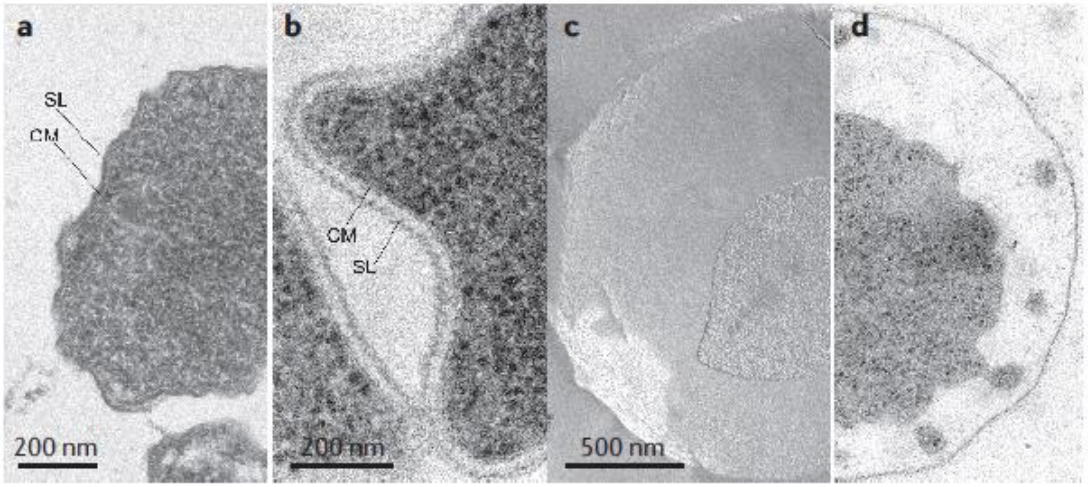
- Targeting the right organisms

Standard lab organism

Laboratory organism

System relevant organisms

Very diverse population, incl. both Bacteria and Archaea



Testing biocide efficiency

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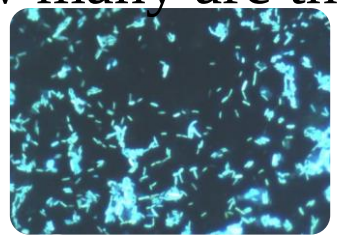
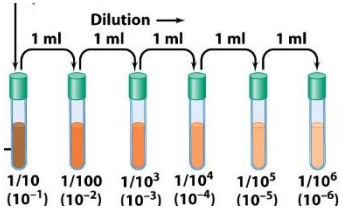
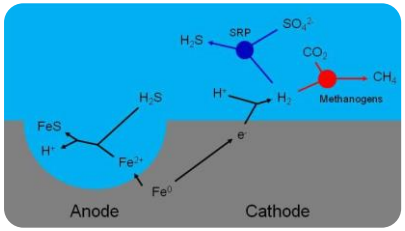
- Targeting the right organisms
- Analysis for measuring efficiency

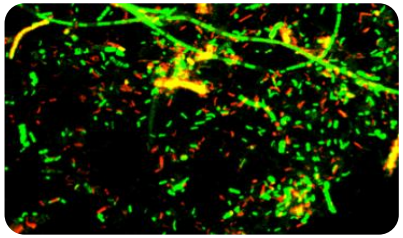
How many are there?



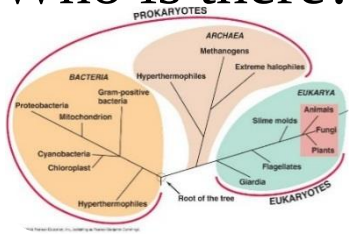


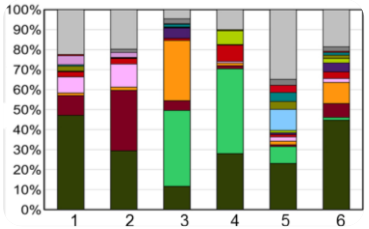
How active are they?





Who is there?





Testing biocide efficiency

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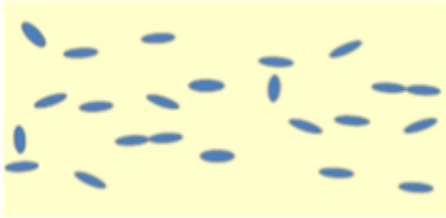
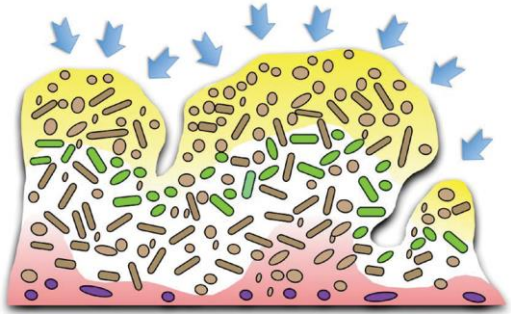
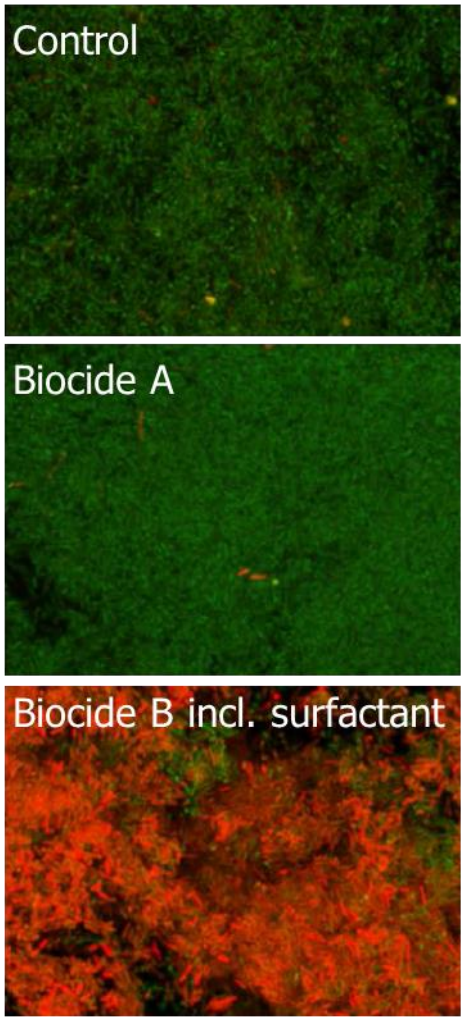
- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm

Free planktonic cells



Microbes grow in biofilm





Alive cells ; Dead cells

Testing biocide efficiency

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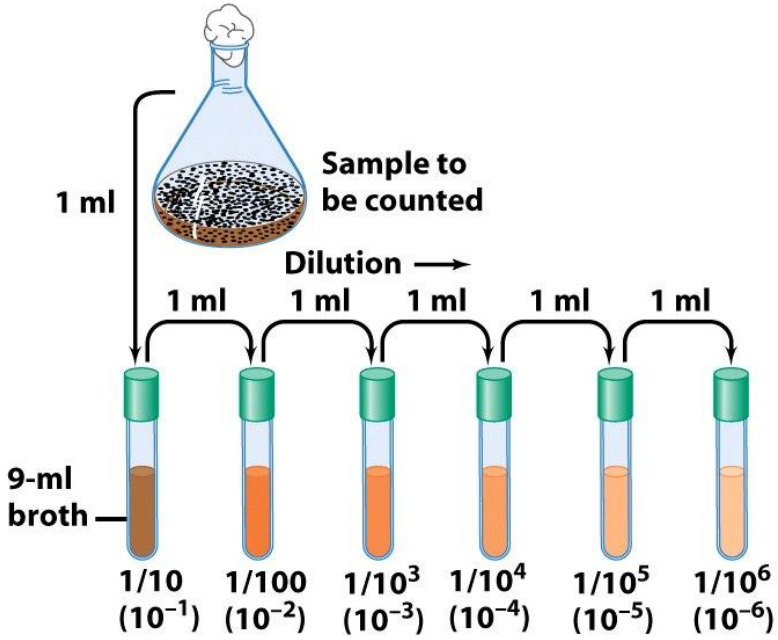
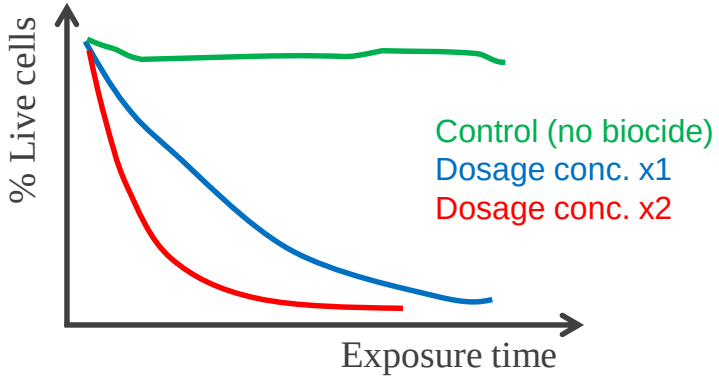
- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm





NACE TM0194-2014

Planktonic tests are common practice, but results are not valid for biofilms!

Tests with biofilm are recommended!

Further recommendations:

- Use water from offshore system
- Investigate for signs of water/system incompatibility
- Verify by coupon or system monitoring

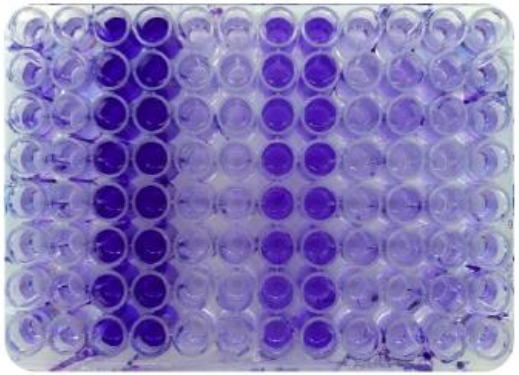
Testing biocide efficiency

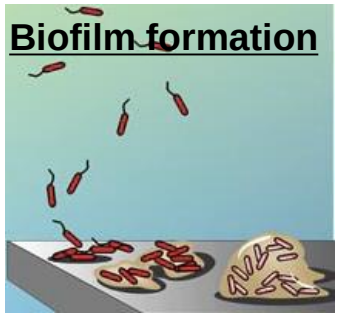
DANISH TECHNOLOGICAL INSTITUTE

- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm

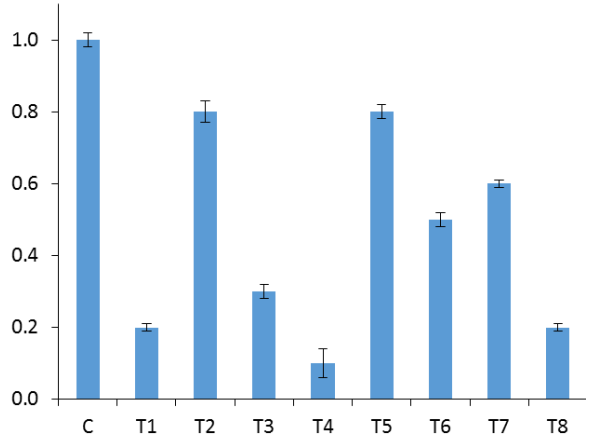
Biofilm screening test:

- Ranking of large number of biocides
- Influence from production chemicals





Output



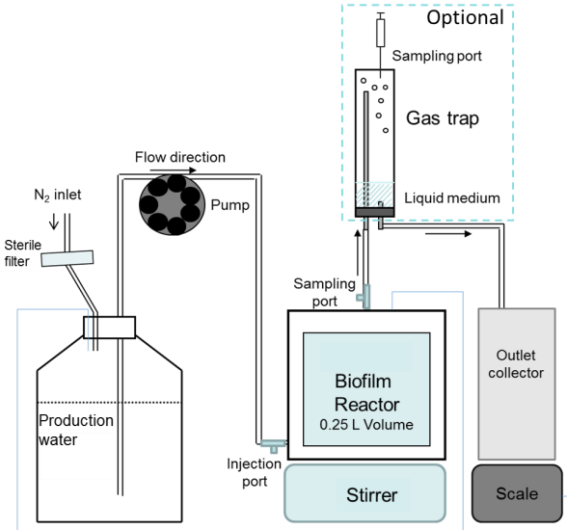
Relative biofilm activity or density compared to a control

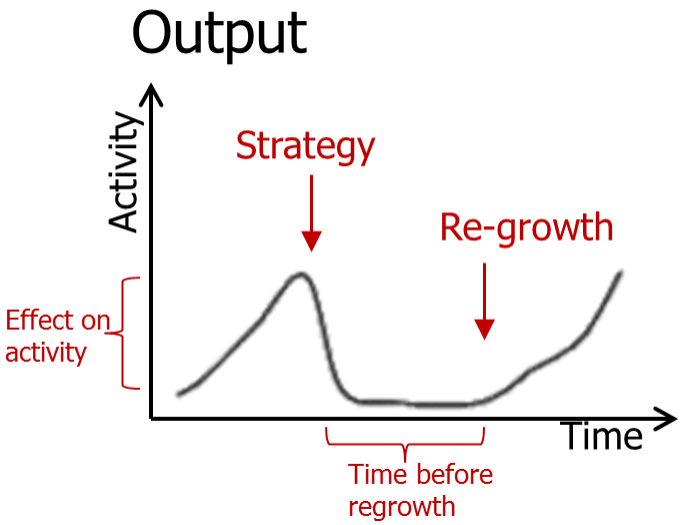
Testing biocide efficiency

- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm

Clean carbon steel *System–related methanogen*

Optimization of biocide dosage regimes





Biocide selection and considerations

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1. Biocides compatibility

Sample from system

→ *Selection of potential biocides*

Evaluation of injection points

→ *Which biocides are stable in the specific system and for how long*

2. Choice of biocides

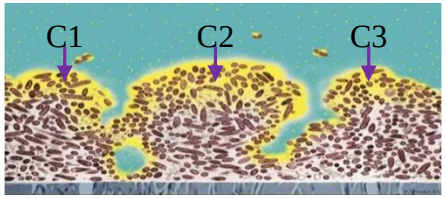
Sample from system

→ *Identification of microorganisms*

→ *Screening of potential biocides*

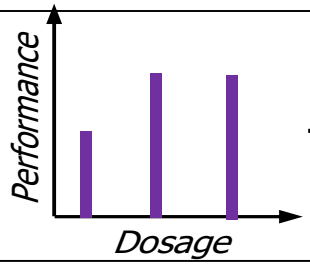
→ *Selection of best-in-class biocide(s)*

3. Dosage concentration



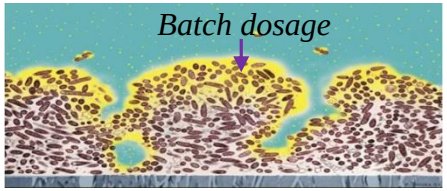
Lab-scale biofilm

→



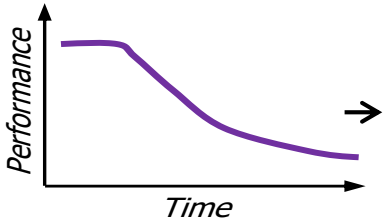
→ *Selection of minimum dosage concentration giving best performance*

4. Dosage frequency



Lab-scale biofilm

→



→ *Selection of optimal dosage frequency for sustained biofilm control*

5. Maximum effect at minimum cost

Case 1 – choise of chemicals

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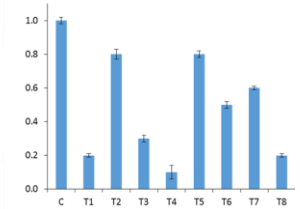
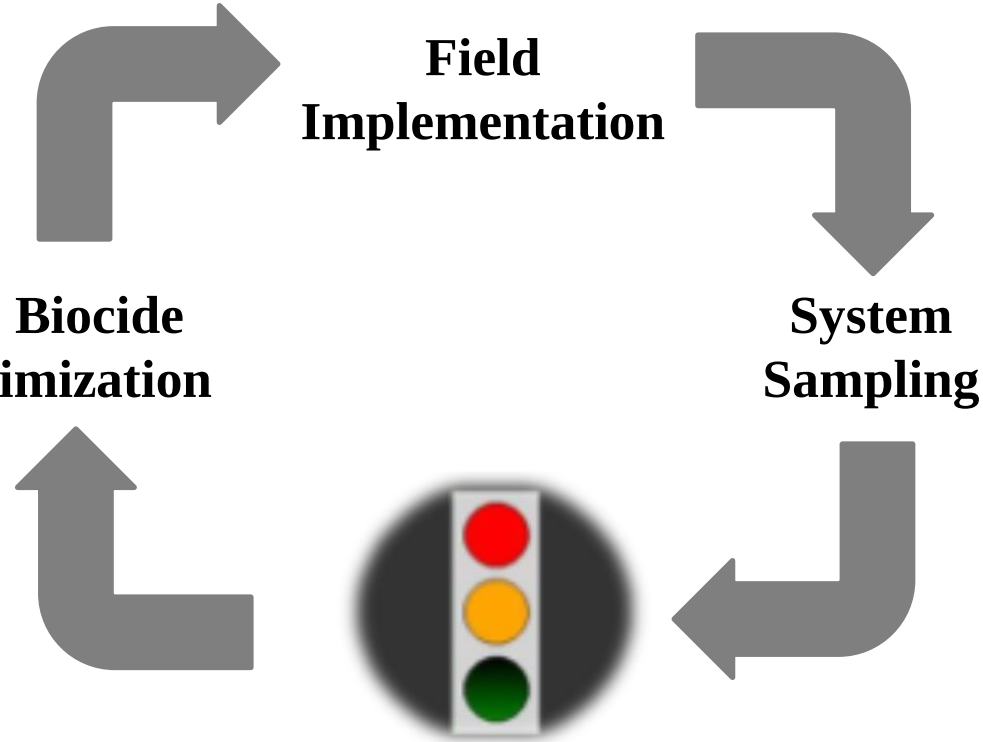
- Example of biocide optimization strategy in produced water where MIC and fouling is experienced.
- Article will be published at NACE 2020.

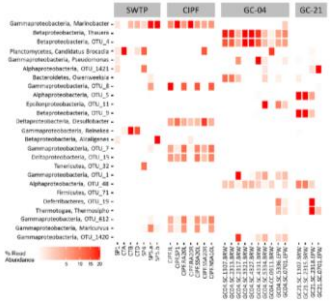
Case 2 - optimization of biocide application

DANISH TECHNOLOGICAL INSTITUTE

- Microbially influenced corrosion in oilfield: microbial quantification and optimization of biocide application (Senthilmurugan *et al.* 2019)







Case 2 - optimization of biocide application

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- Mapping of system microorganisms in system waters
  - SRB (e.g. desulfovibrio and desulfobacter) are abundant in seawater and brackish water systems
  - Acid-producing halo-tolerant (e.g. Halanaerobium spp.) was abundant in effluent waters

- Laboratory enrichments targeting identified troublesome microorganisms

Case 2 - optimization of biocide application

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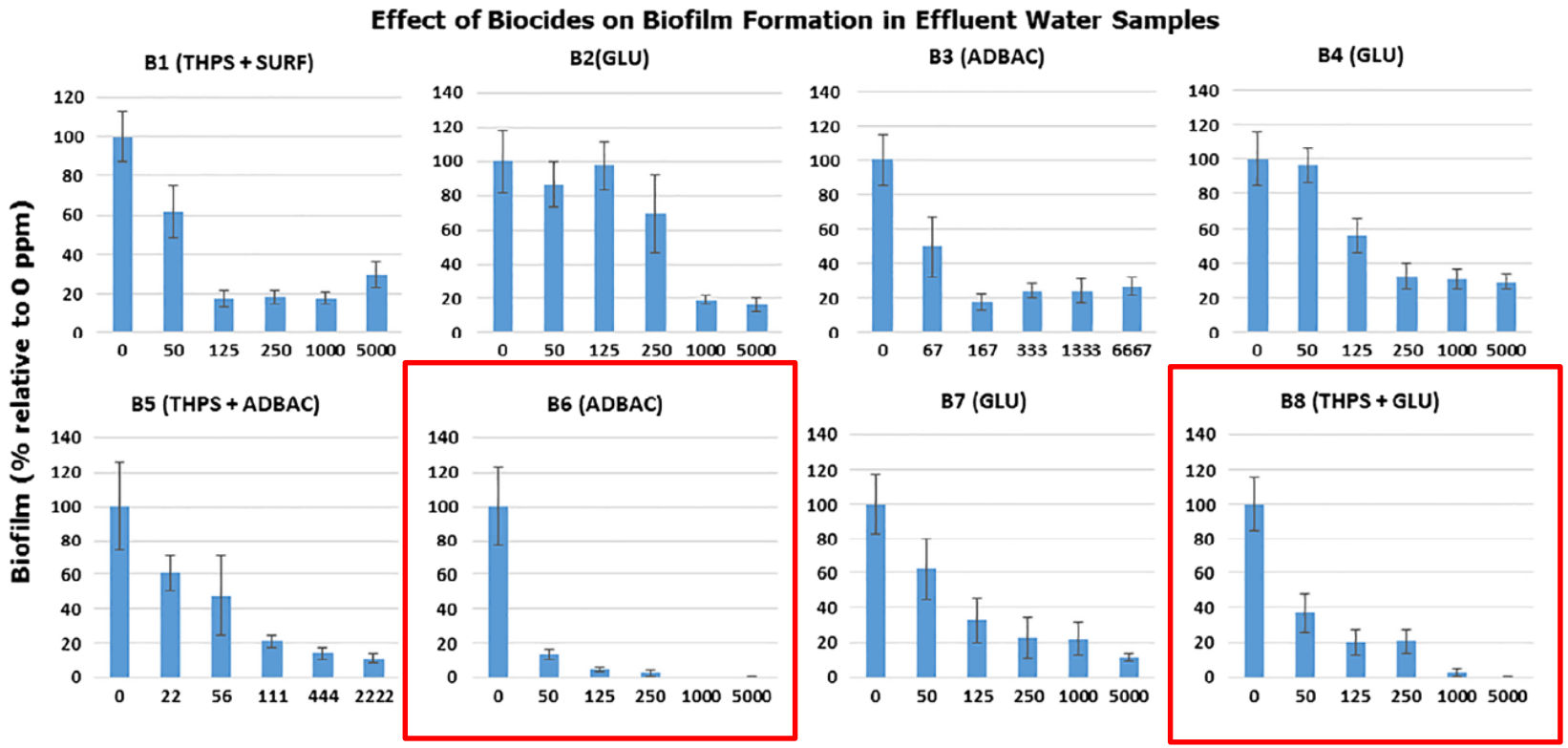
- Biocide screening with system-derived biofilms for each of the three water types



Case 2 - optimization of biocide application

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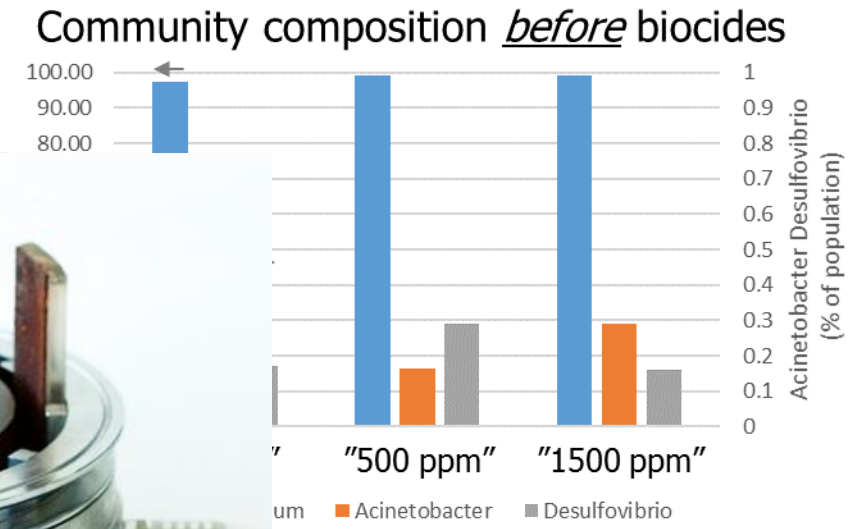
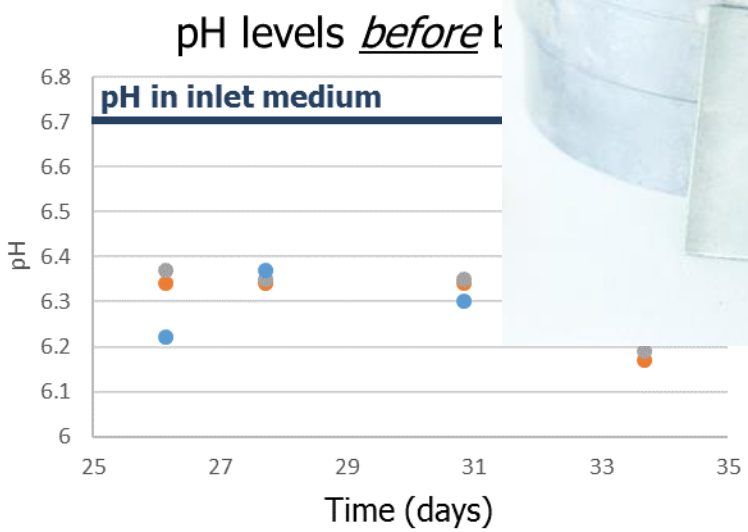
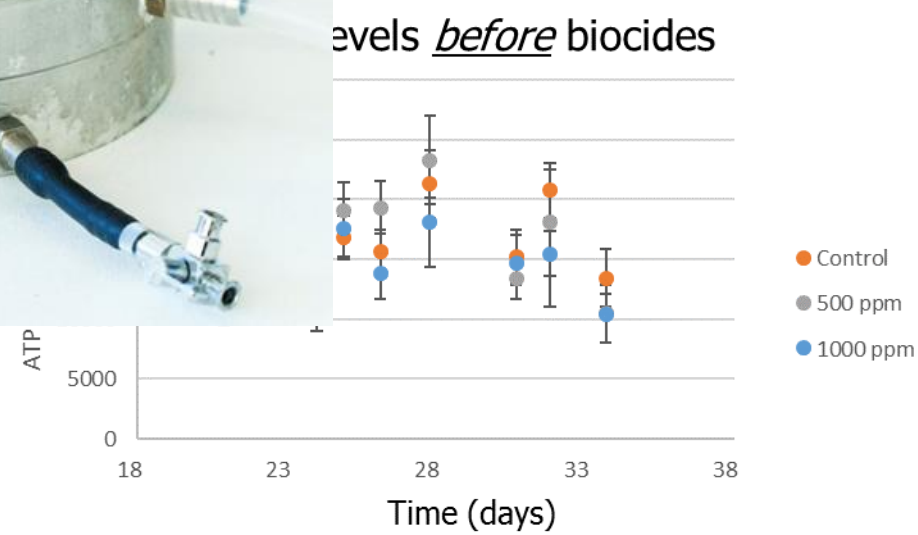
Before biocide challenges

- pH reduced in
- Natural fluctua
  (ATP signal)
- Acid-producing
  Haloanaerobiu
- SRB *Desulfovib*
  but H_2S not de







Case 2 - optimization of biocide application

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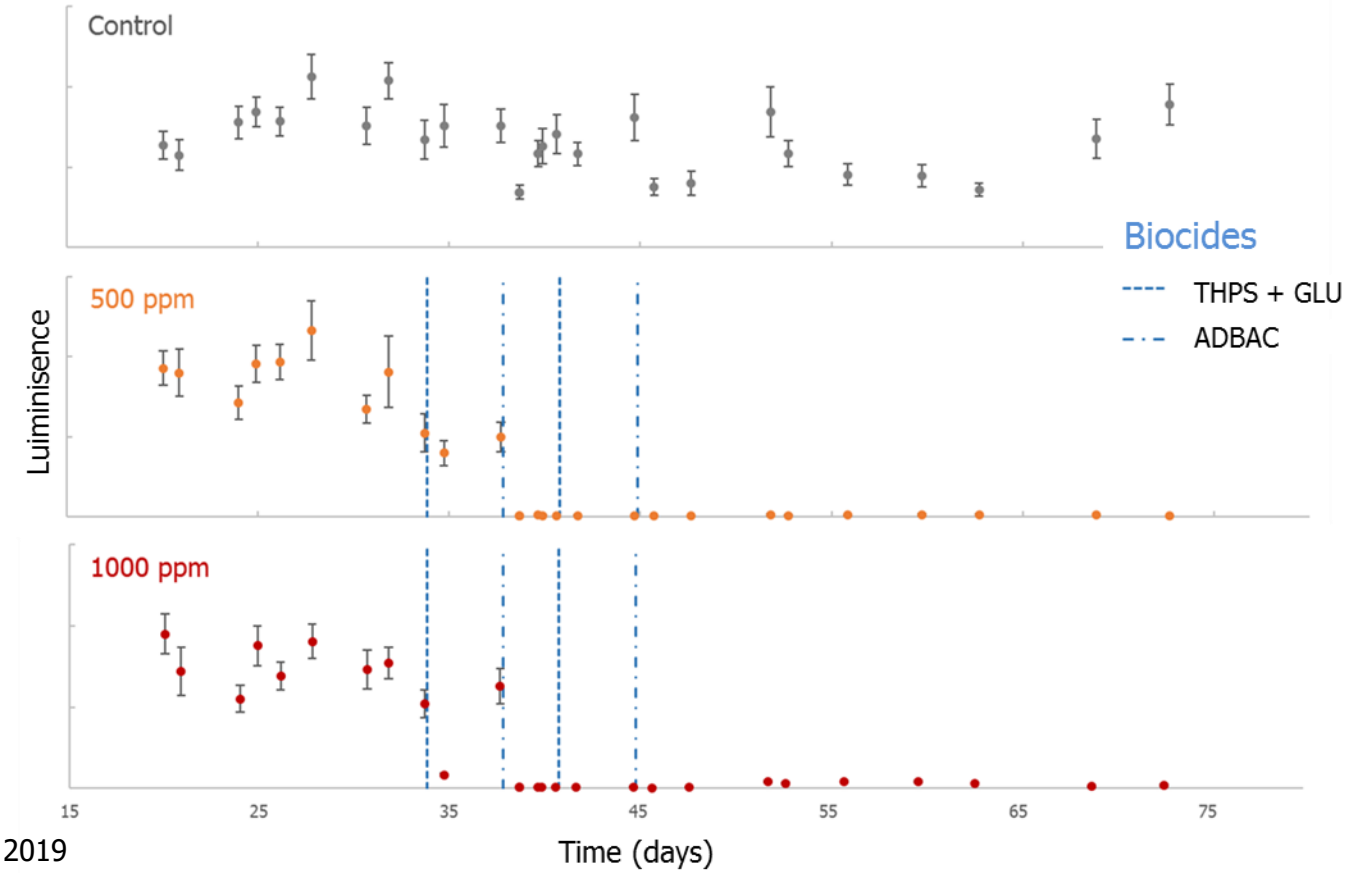
- Biocidal effect on microbial activity (levels of ATP) in effluent waters
  - Temporary effect of THPS + GLU blend
  - Long-term effect of ADBAC



Case 2 - optimization of biocide application

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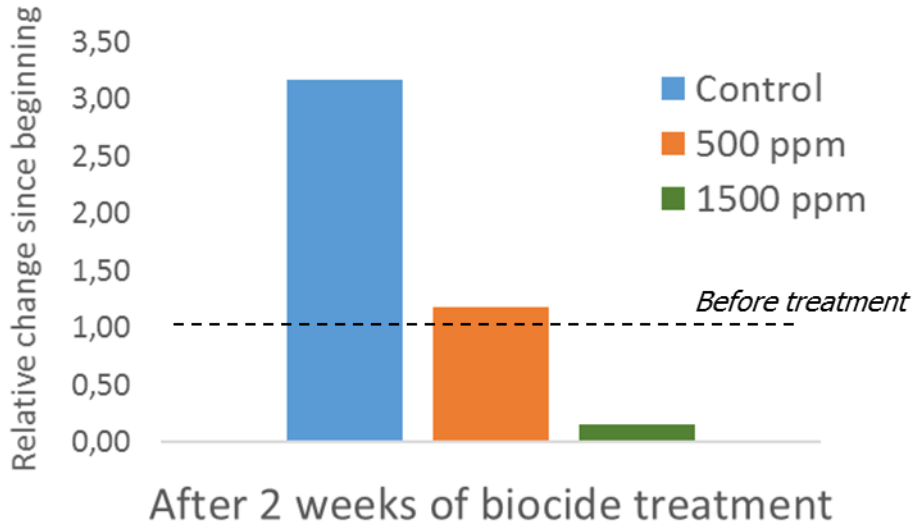
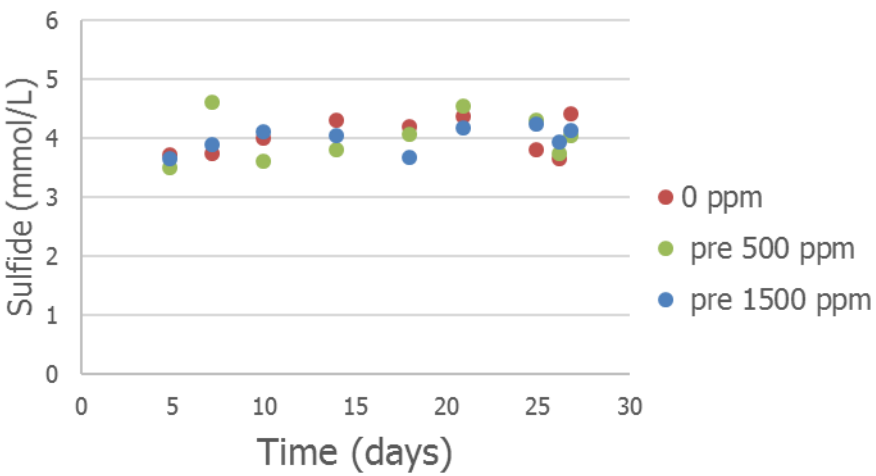
Seawater enrichment in biofilm reactors treated with two biocides

Microbial numbers and activity

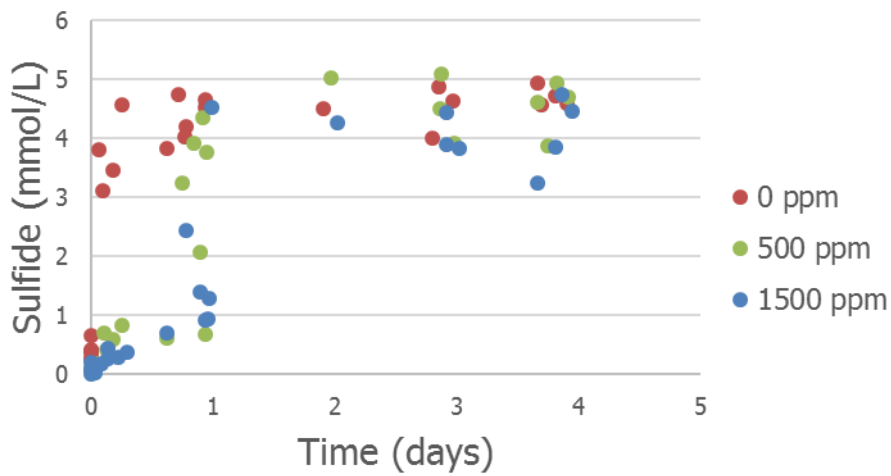
- 500 ppm → growth "under control"
- 1500 ppm → numbers decreased
- SRB activity increased within a day after biocide treatments



Sulfide concentation *before* biocides



Sulfide production *after* biocides



Case 2 - optimization of biocide application

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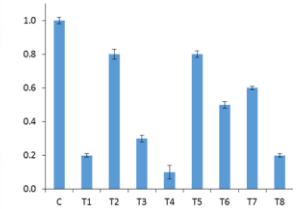
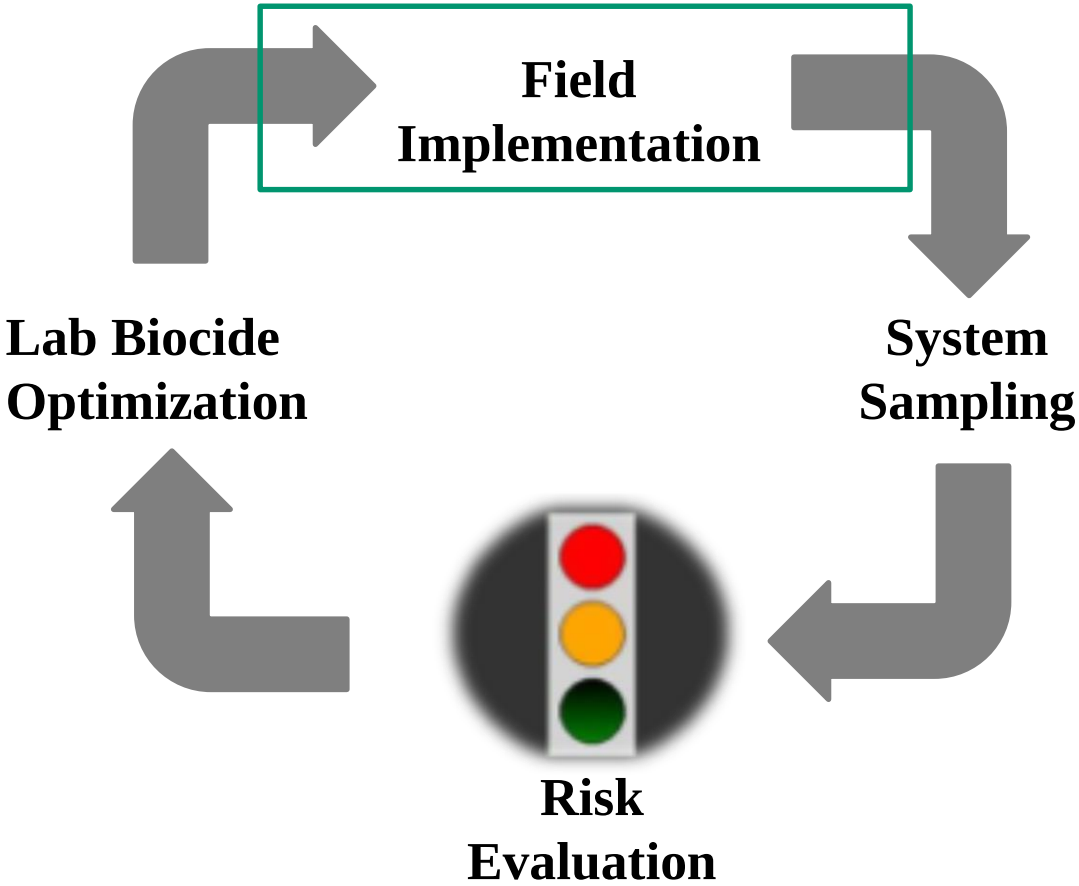
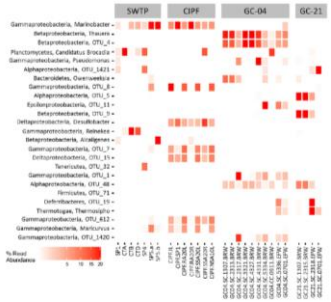
- Next step – field implementation







Case 3 – effect of operational decisions - field monitoring

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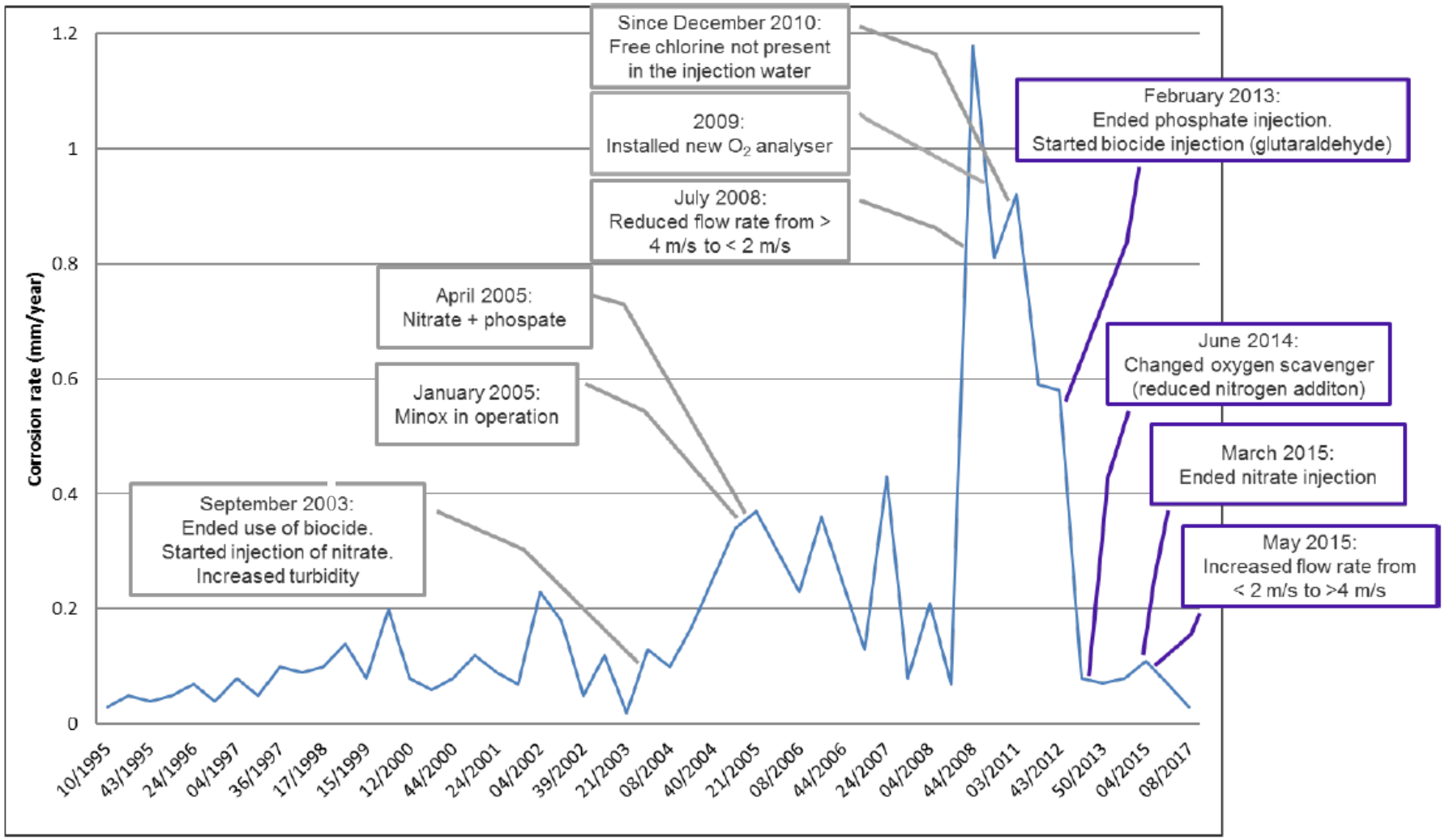

Liengen *et al*. 2017 Eurocorr

Chemical management of Pipeline MIC: strategies for improved mitigation

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Needed considerations for improved MIC mitigation

- MIC Mitigation concerns control of biofilms
- Biocides should reach pipelines – combination with pigging is beneficial
- Ensure that biocides are compatible with system waters, applied production chemicals (e.g. oxygen and H_2S scavengers), materials

Recommended strategies for improved MIC mitigation

- Biocides should be effective towards troublesome biofilm from the system
- Monitor effect when new mitigation strategies are implemented
- Alternate between two or more biocide products to avoid promoting development of microbial resistance

Thank you for you attention

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INSTITUTE OF CORROSION

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empowered by technology

ICORR ABERDEEN BRANCH WELCOMES

Inspecting for MIC

Presented By Daniel Sandana, Principal Corrosion Engineer

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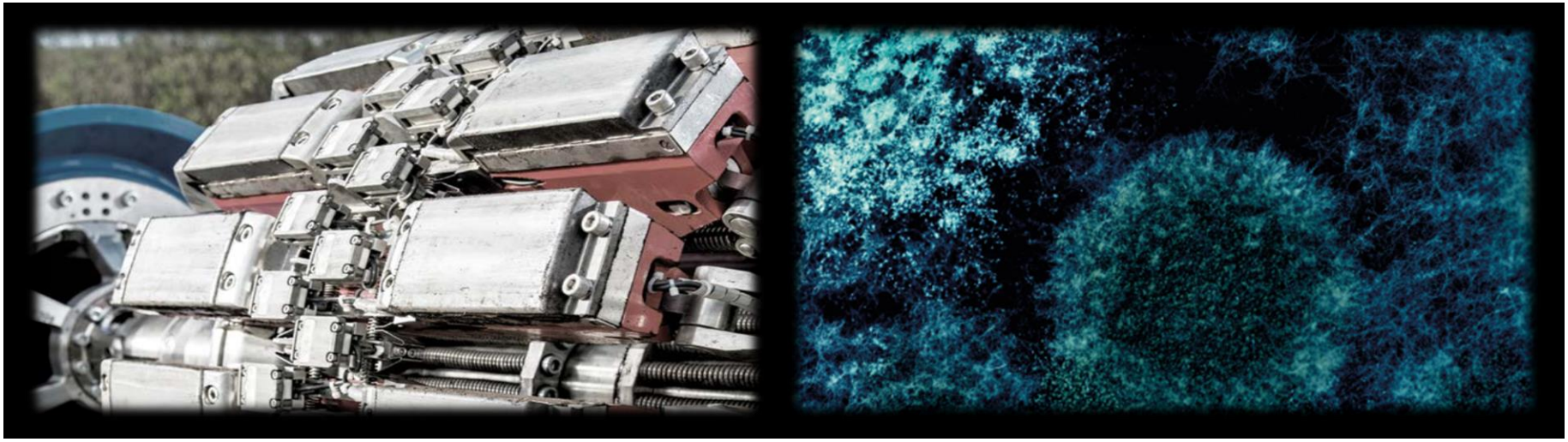

CONTENT

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- *could we physically inspect for MIC reliably to prevent failure?*
- *Are there any MIC defects we could not inspect and manage in suitable time to prevent leaks with traditional tools?*
- *Are Inspection tools and schemes sufficient to manage identify the threat of MIC and manage MIC?*

1. Review of MIC morphologies…
2. Traditional ILI Vs ID/Sizing of MIC… any limitations?
3. New advances for MIC ID/Sizing?
4. Is ILI sufficient to manage MIC?
5. Conclusions

MIC MORPHOLOGIES…
ONE UNIQUE?

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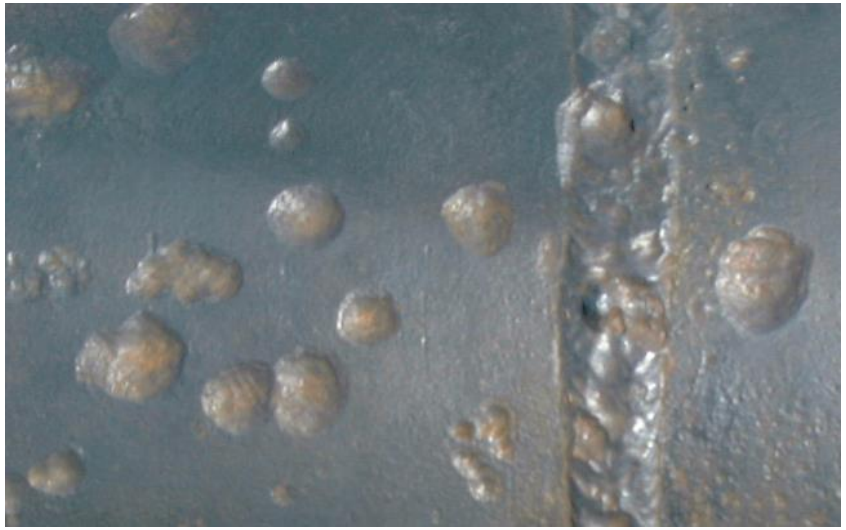
Most commonly associated with MIC?



✓ Pit of semi-hemispherical (scoop) shape…

… but not the only one…

MIC MORPHOLOGIES…
OTHERS SEEN…

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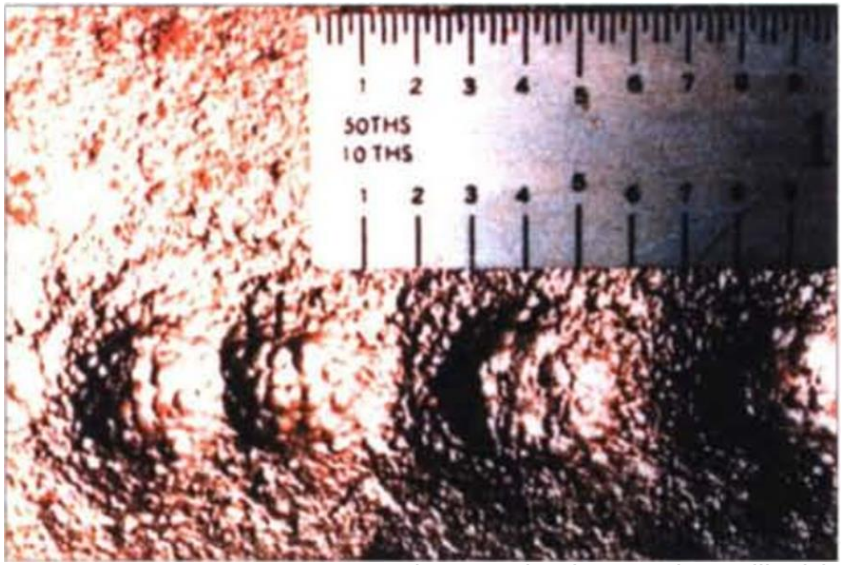
A slight variation



(Gas Technology Institute, Illinois)

- ✓ Typical Cup-type scooped out hemispherical pits with crater in pit

MIC MORPHOLOGIES…
OTHERS SEEN…

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A completely different one

- ✓ Large craters surrounded by uncorroded metal

MIC MORPHOLOGIES…
OTHERS SEEN…

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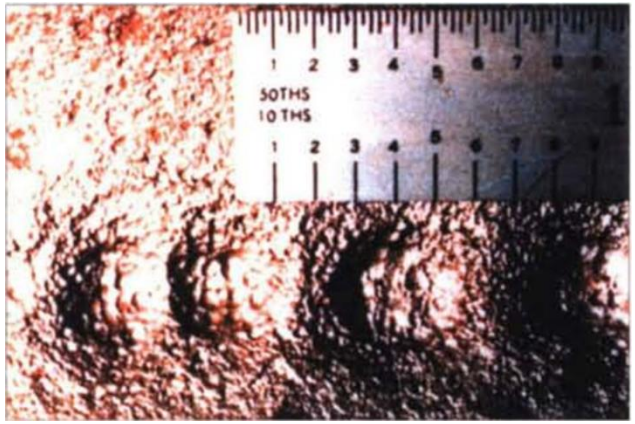
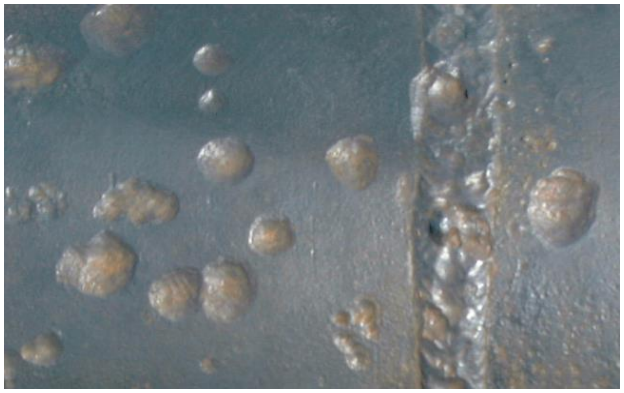
Another completely different one

- ✓ Striations or contour lines in the pits or craters also running parallel to the longitudinal axis of pipe

MIC MORPHOLOGIES…
OTHERS SEEN…



- ✓ No diagnostic possible just based on morphologies…..
- ✓ Abiotic vs biotic corrosion morphologies…



PIPELINE INTEGRITY MANAGEMENT & CORROSION…

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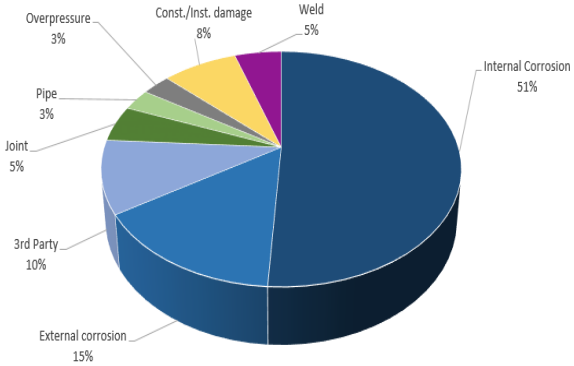
- ✓ Where? … Locations…. Axial/circumference distribution
- ✓ What?... Shape... morphology… Pit? General? Crack?
- ✓ How much?... Severity
- ✓ Active or non-active? … Corrosion growth

Corrosion hot spots



Mitigation… Repairs … Rehabilitation plans…

TRADITIONAL PIPELINE ILI TECHNOLOGIES
…FOR METAL LOSSES

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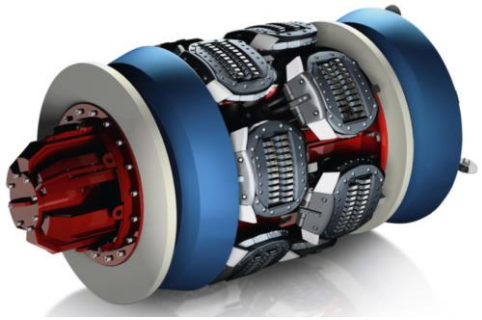
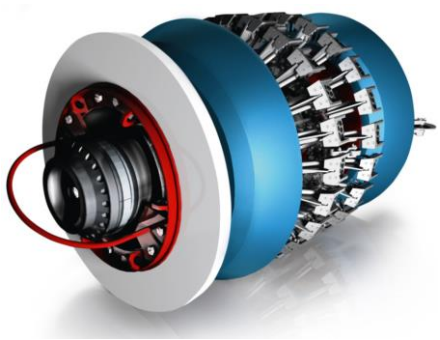
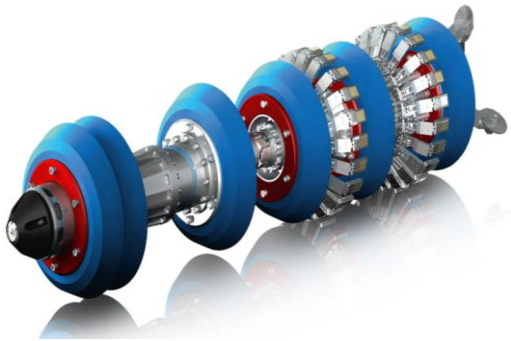
RoCorr MFL-A



RoCorr MFL-C

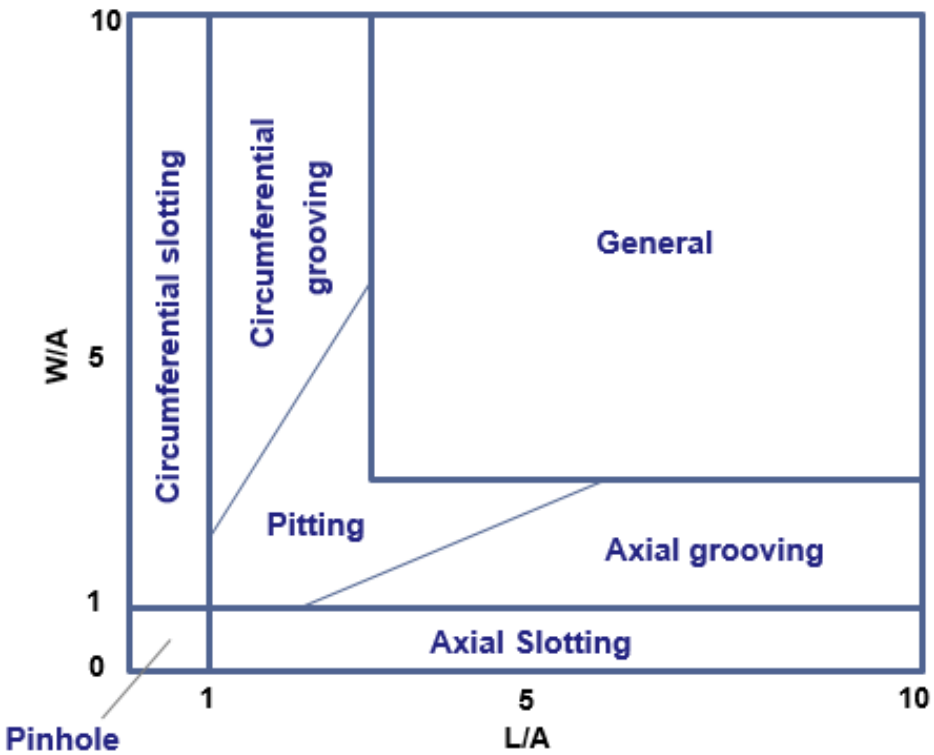


RoCorr UT



RoCorr SIC

TRADITIONAL ILI …
LIMITATIONS?



Metal Loss Feature Type Definition by POF

W: Width
L: Length

If NWT < 10 mm, then A = 10 mm
Else A = NWT

- Each metal loss technology is best suited for certain types of morphologies.

TRADITIONAL ILI …
LIMITATIONS?

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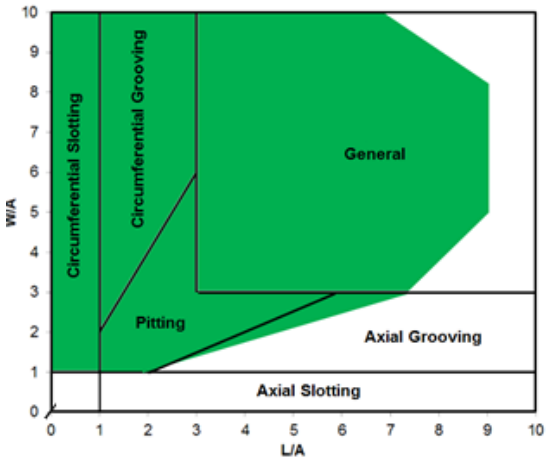
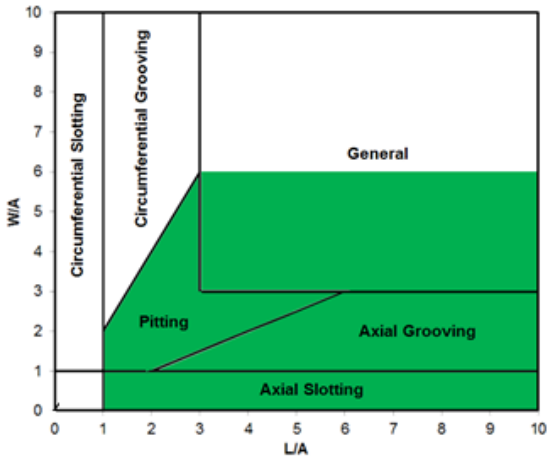


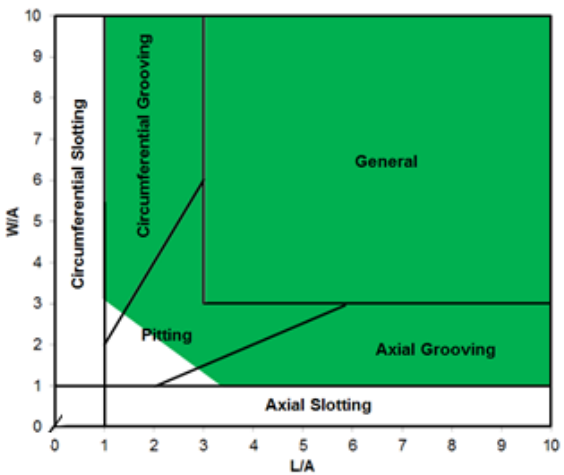
MFL-A

Better able to detect and size features with a greater circumf. profile



MFL-C

Better able to detect and size features with a greater axial profile



Compression wave UT

Able to detect and size larger areas of metal loss (e.g. general corrosion, channelling)

(Eddy current technology… shallow internal corrosion of minor sizes)

TRADITIONAL ILI …
LIMITATIONS?

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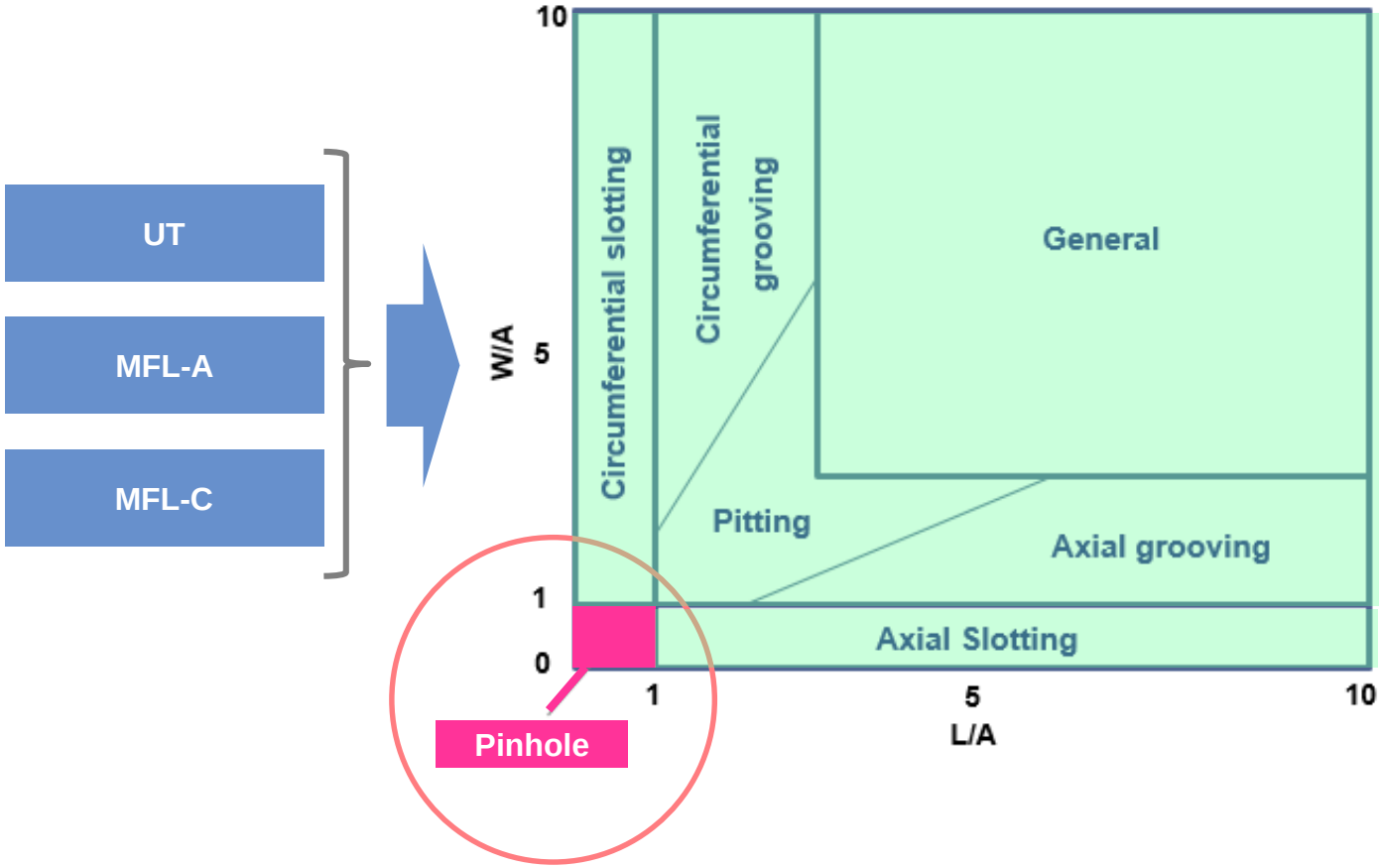

…all but the smallest metal loss features are detectable…

MIC MORPHOLOGIES VS ILI CAPABILITY…

- **Can MIC defects be detected/sized by traditional ILI?**

CAN MIC DEFECTS BE DETECTED/SIZED BY TRADITIONAL ILI?

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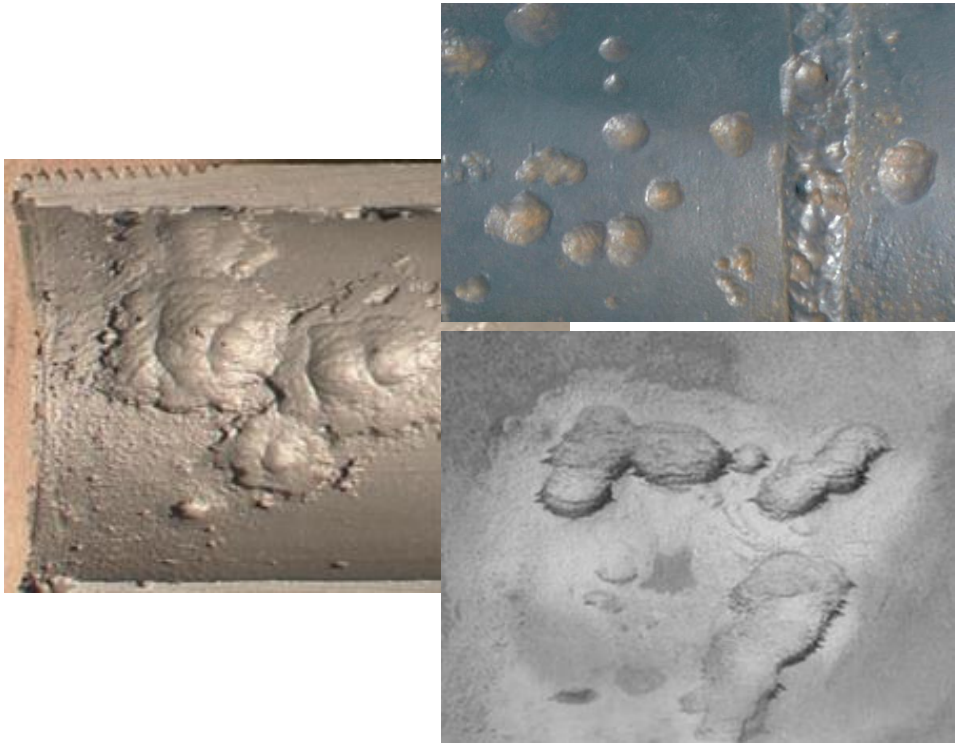

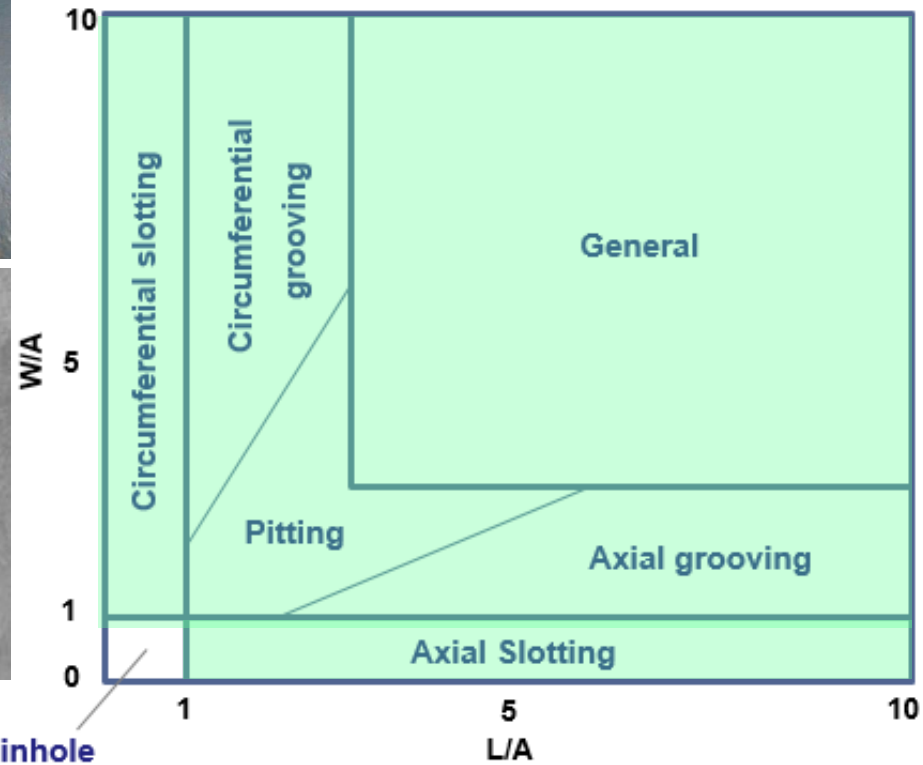

Many occurrences … MIC can be detected and sized by traditional ILI …

CAN MIC DEFECTS BE DETECTED/SIZED BY TRADITIONAL ILI?

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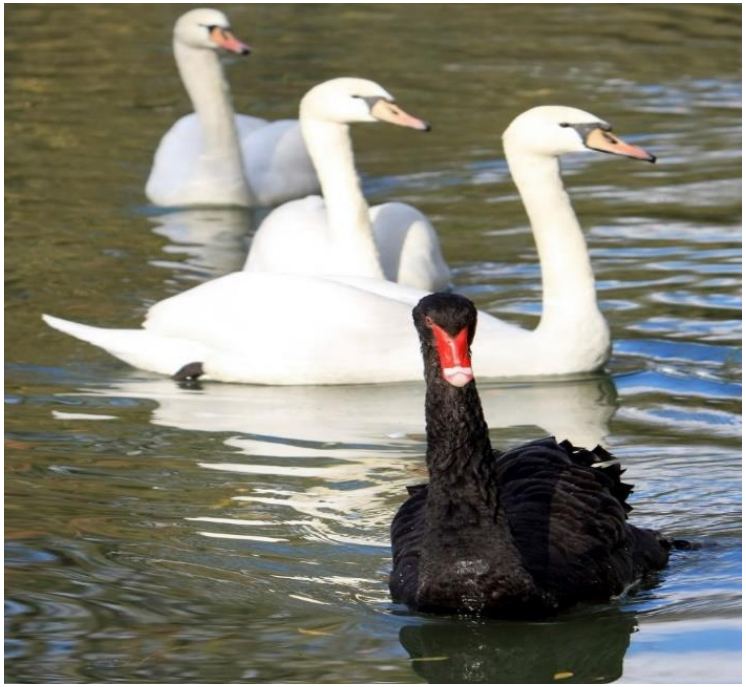

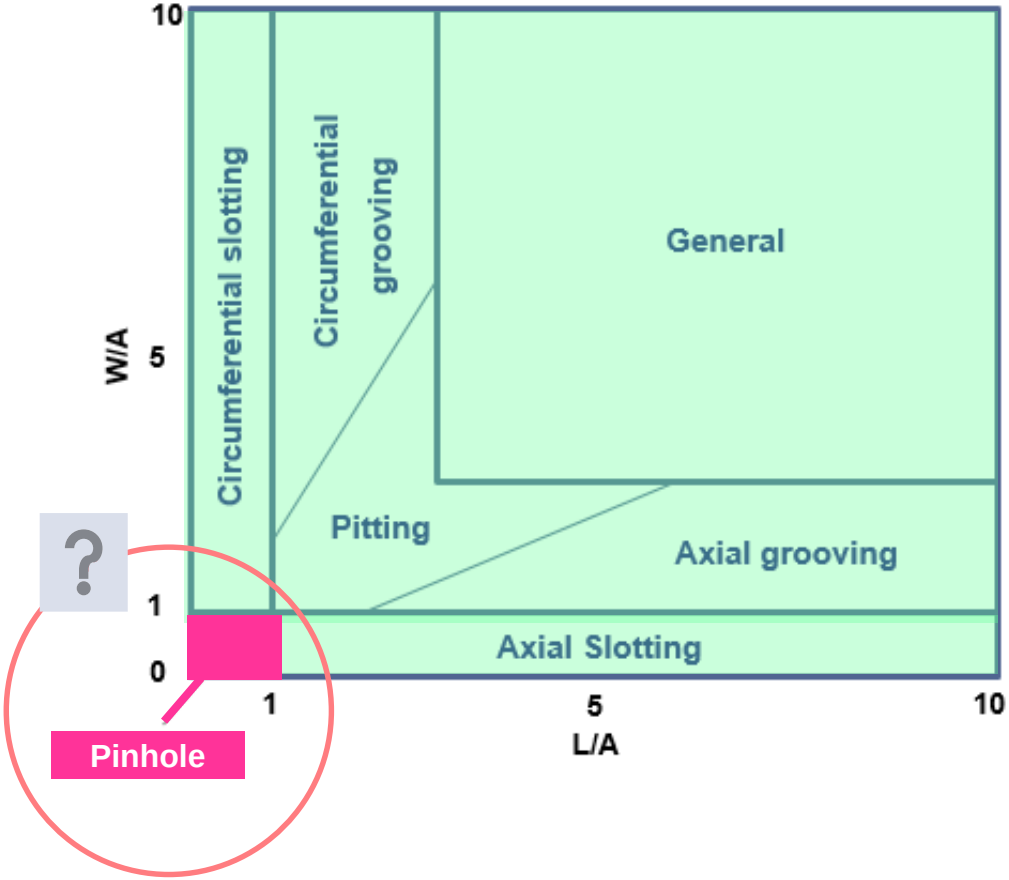

Many occurrences … MIC can be detected and sized by traditional ILI …

HOWEVER…
MIC & PINHOLES…

Pinhole leaks

In North Sea WI due to MIC

…Can not be ID/sized by traditional ILIs…

HOWEVER…
MIC & PINHOLES AT COMPLEX CORROSION CLUSTERS…

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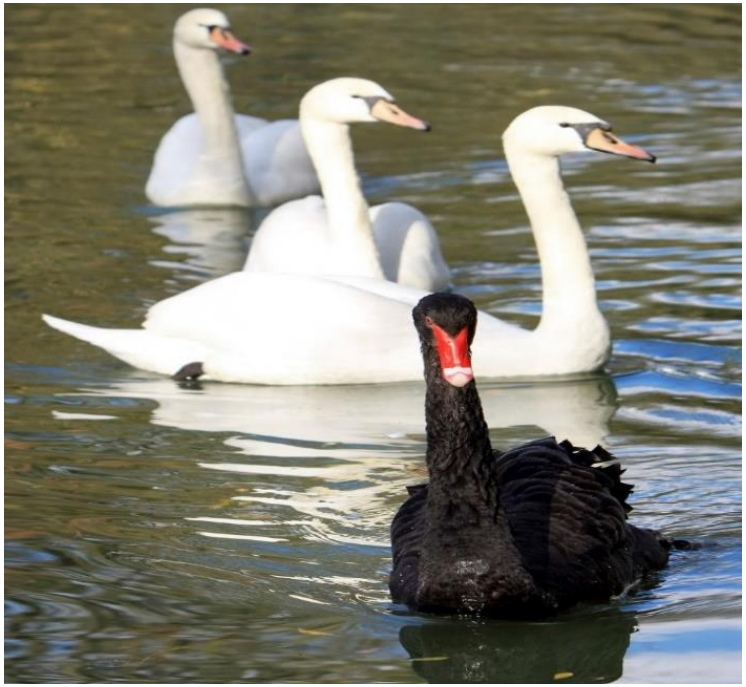
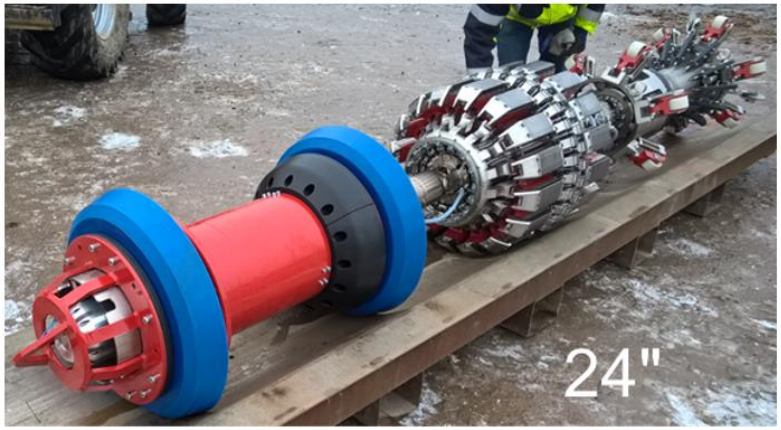


…Can not be reliably ID / sized by traditional ILIs…

ANY ILI SOLUTIONS FOR MIC PINHOLES & COMPLEX CORR. CLUSTERS? … MFL ULTRA…



Circumferential Resolutions of common inspection technologies

MFL-A	Ultrasonic	MFL-A Ultra	3D Laser Scan
4-6 mm	4 mm	1.6 mm	1-2 mm

ANY ILI SOLUTIONS FOR MIC PINHOLES?
… MFL ULTRA…

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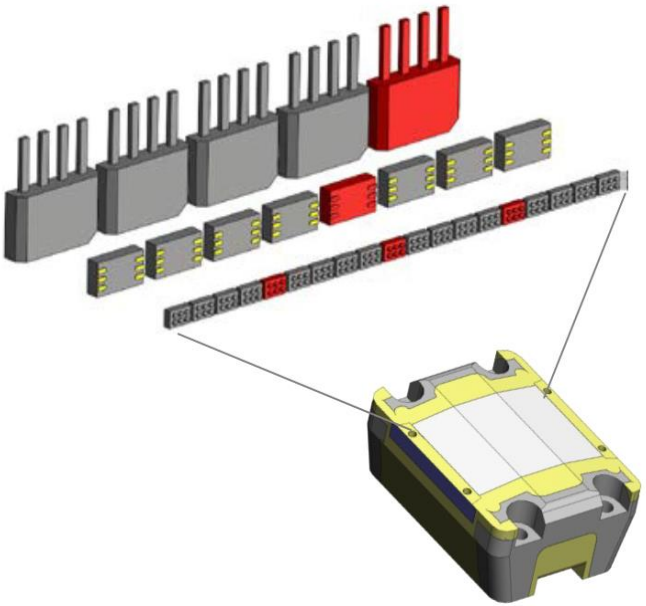
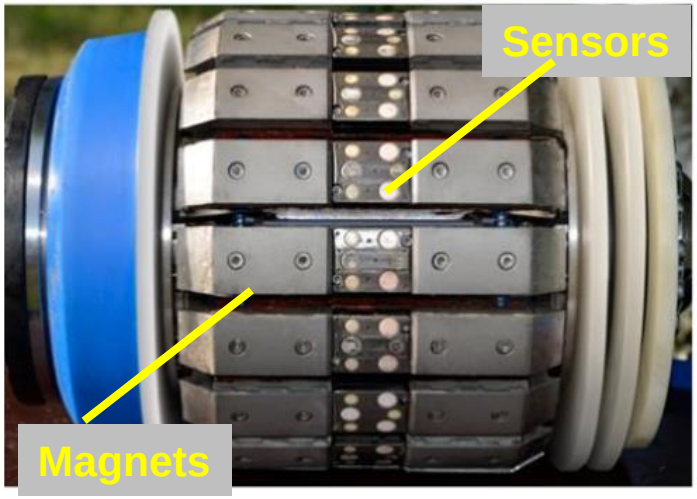
- ✓ **Enhanced Ultra-density sensors**…
- ✓ Fully triaxial MFL sensor elements consisting of 3D integrated circuit modules…
- ✓ sensor circumf. spacing of 1.6 mm & axial sampling of 1 mm …
- ✓ factor 10 increase in the number of sensor elements per ILI tool compared to traditional MFL-A ILI
- Sensor suspension optimized for smooth girth weld passage

Pipeline Imaging resolution close to that of Laserscan reports



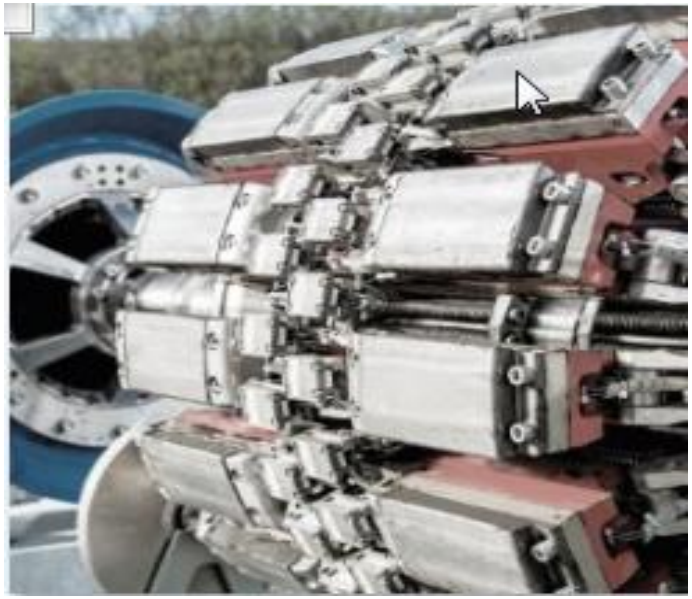
MFL-A ULTRA
… IMPROVED TOOL MECHANICS

Dual sensor ring of MFL-A Ultra ILI tool as prerequisite to exploit full potential of new sensors



Traditional MFL high-resolution tools

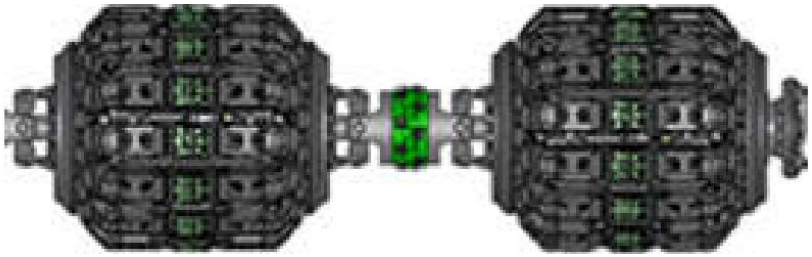
- Sensor carriers placed on one sensor ring
- Carriers located min. 2 mm (0.08 inch) apart because of mechanical constraints



MFL-A Ultra tool

- Two sensor rings within magnetic yokes
- Improved axial track precision

MFL-A ULTRA
… IMPROVED TOOL MECHANICS



- ✓ Two magnet units for sizes from 8’’ to 18’’:

10’’ MFL-A Ultra Tool

- ✓ Two staggered sensor rings in one magnet unit for sizes ≥ 20’’:

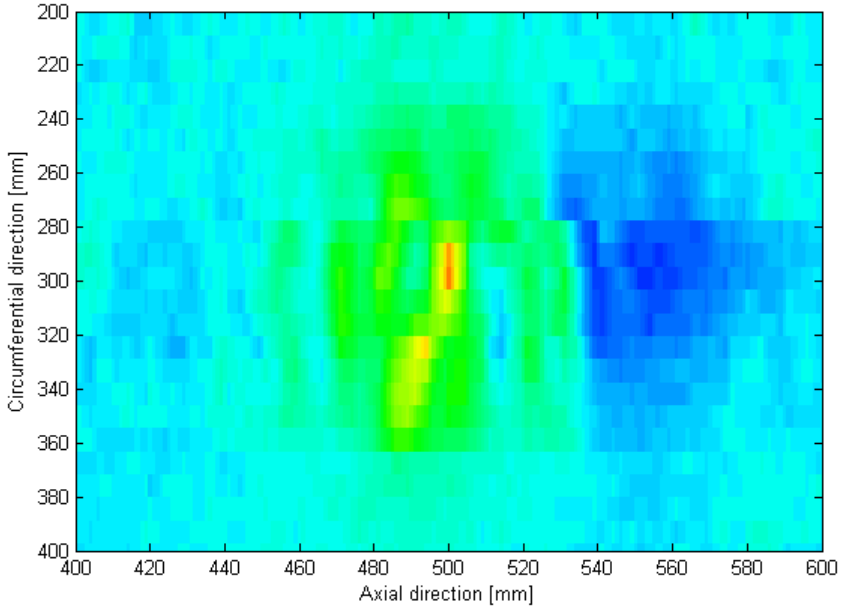
24’’ MFL-A Ultra Tool

MFL-A ULTRA
… FROM A LINE PLOT TO AN AREA PLOT

Example: 1-dimensional lineplot – **complex corrosion feature**

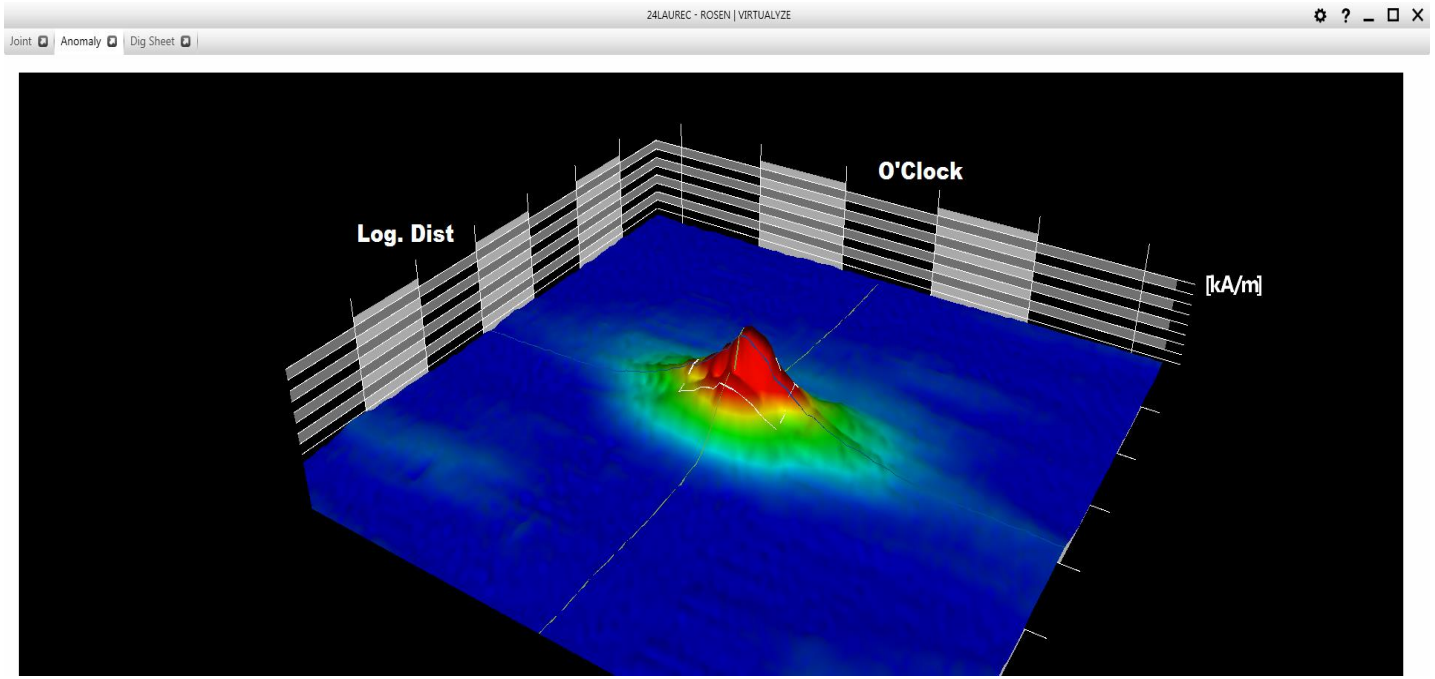
ROCORR MFL-A VS. ROCORR MFL-A ULTRA

- Example: about palm-sized **complex corrosion**

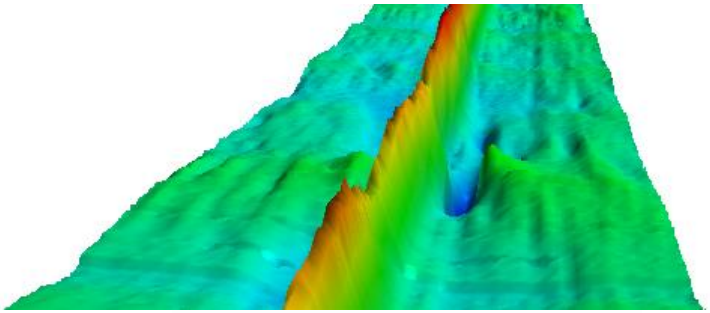


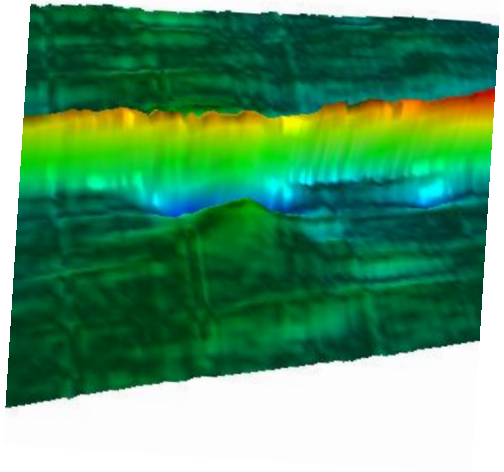
COMBINED 3D MAGNETIC RESPONSE

3D PIPELINE IMAGING™



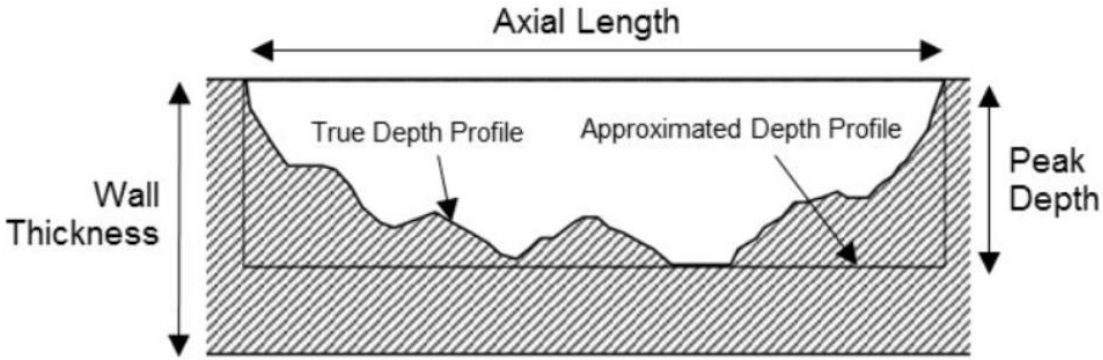
MFL A ULTRA…
COMPLEX CORROSION FEATURE RESOLUTION

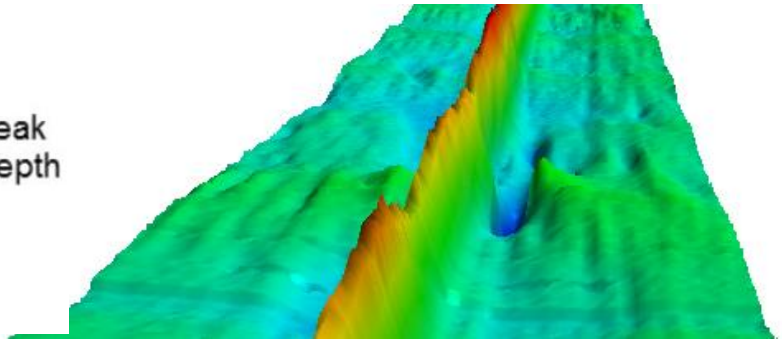


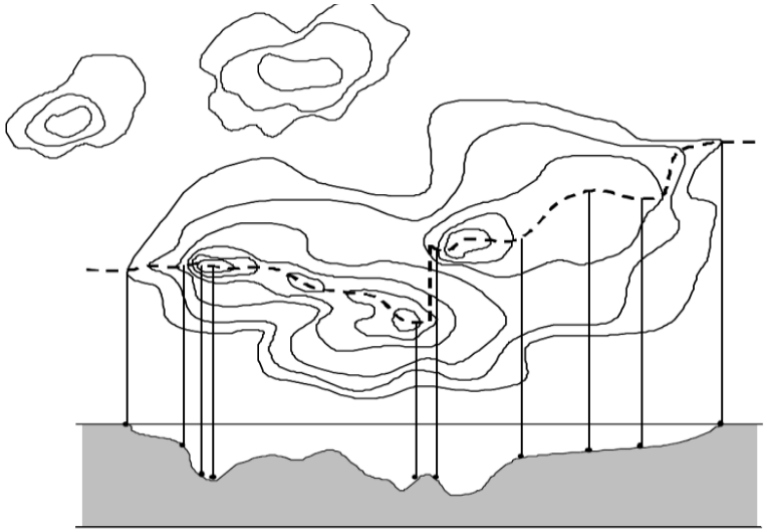


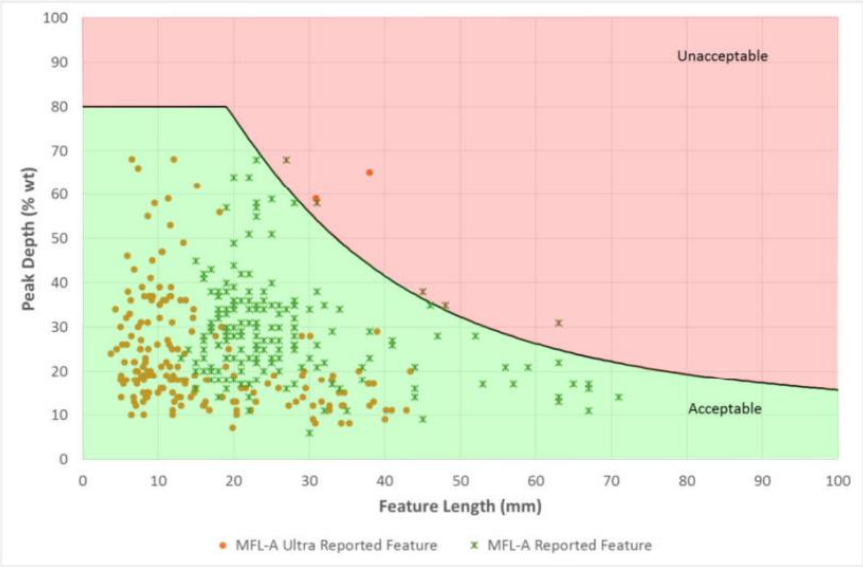
- Carriers mounted in slightly offset fashion to achieve desired circumferential resolution

MFL A ULTRA…
COMPLEX CORROSION FEATURE VS FFS







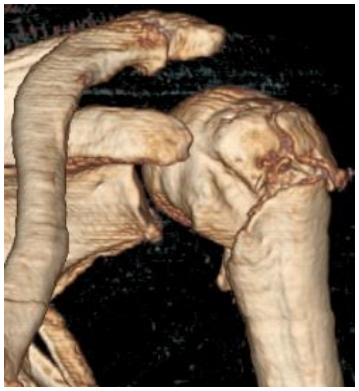


TECHNOLOGY ADVANCES…

Constraints prevailed in medical imaging…

X-Ray

3D CT



…until these were resolved by a step change in technology.

MFL RESULTS LIKE A LASERSCAN

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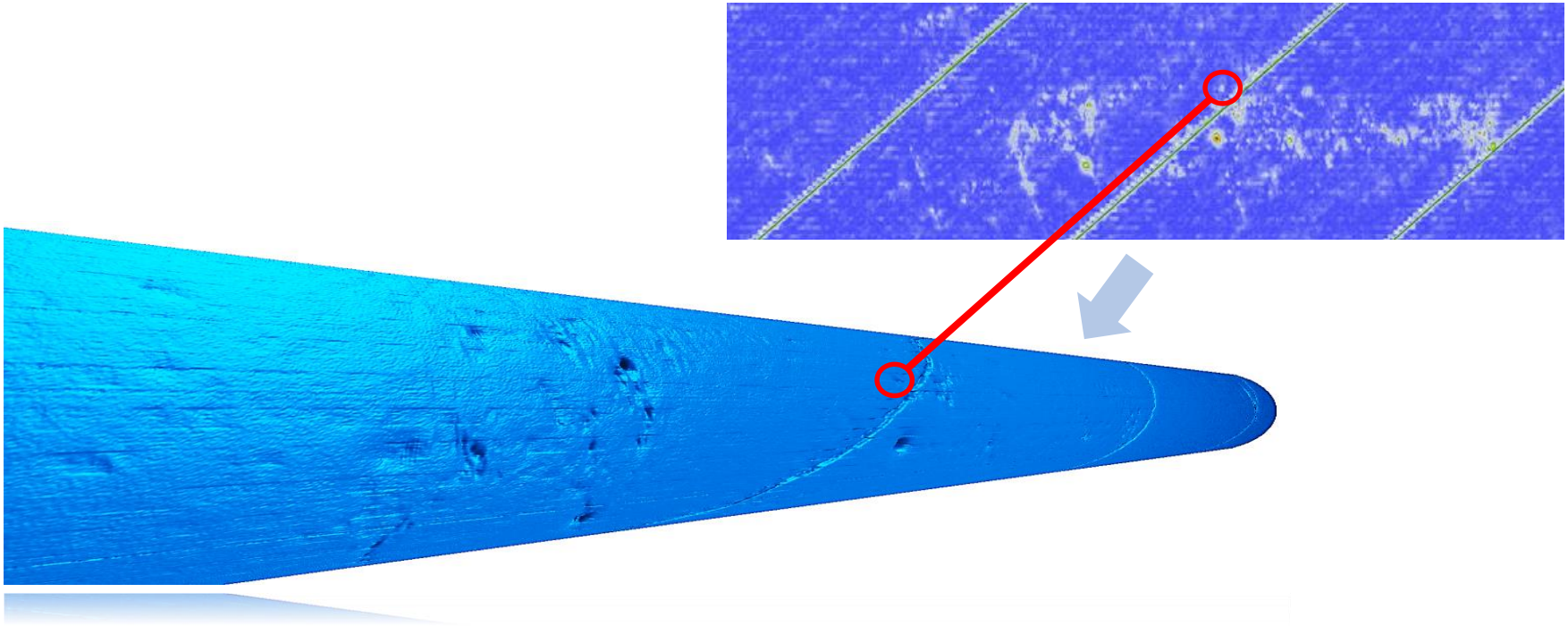
So why not doing the same in ILI?



MIC MORPHOLOGIES VS ILI CAPABILITY…

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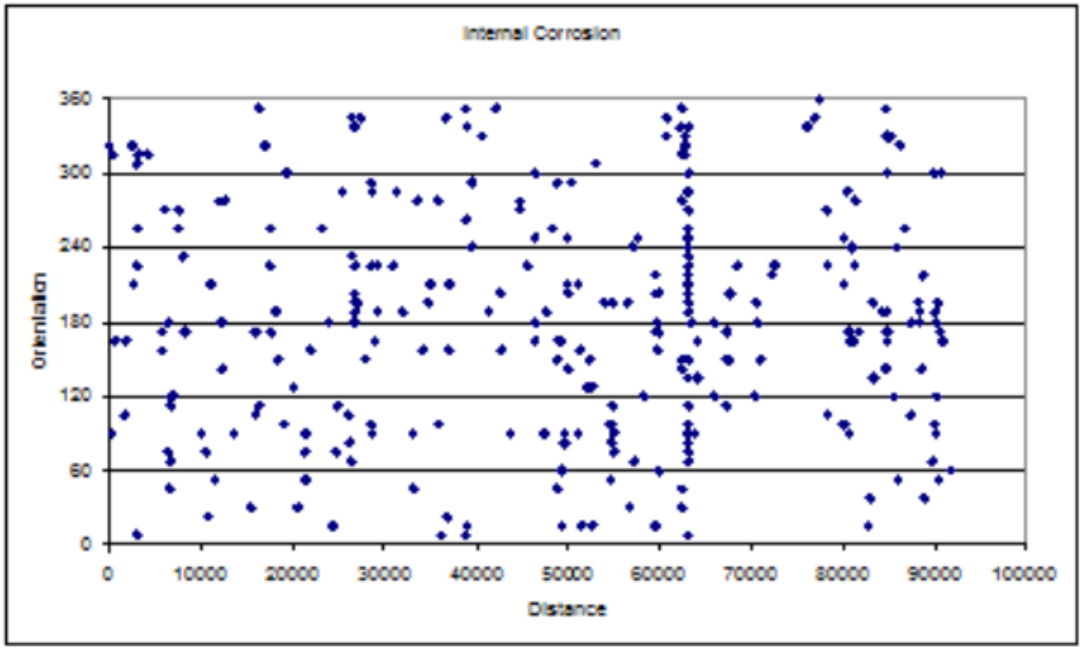
- Is there 1 and unique typical MIC defect morphology?
- Can MIC defects be detected/sized by traditional ILI?

- **Can the sole use of ILI define whether MIC is present in my pipeline?**

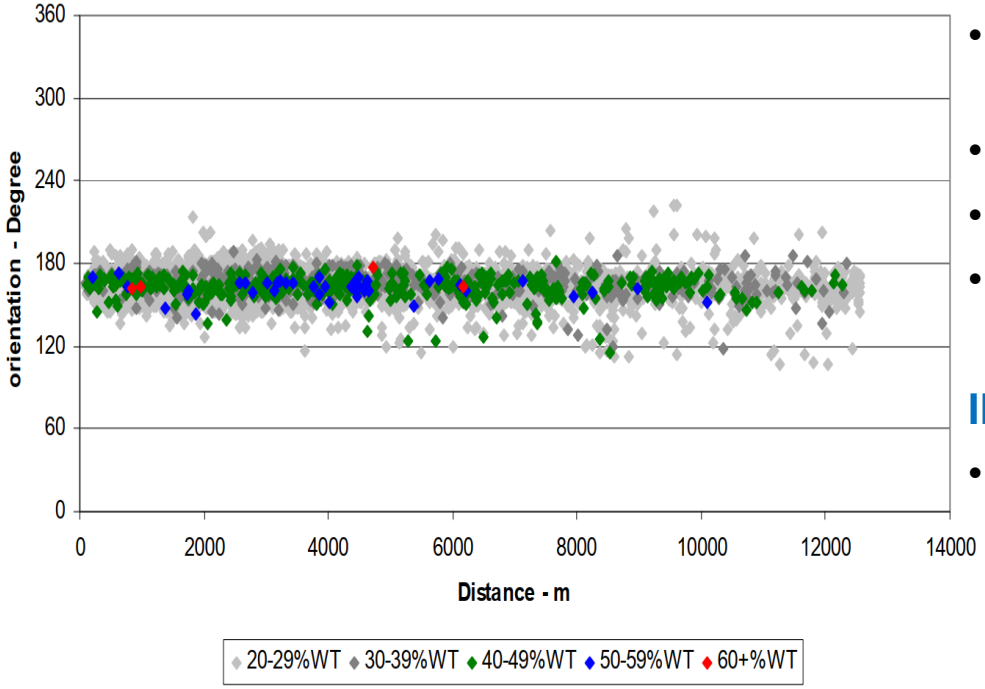
ILI PATTERNS – MIC CASE STUDIES (1)…



Typical pattern for MIC????

….Randomly distributed pits??….

ILI PATTERNS – MIC CASE STUDIES (2)…

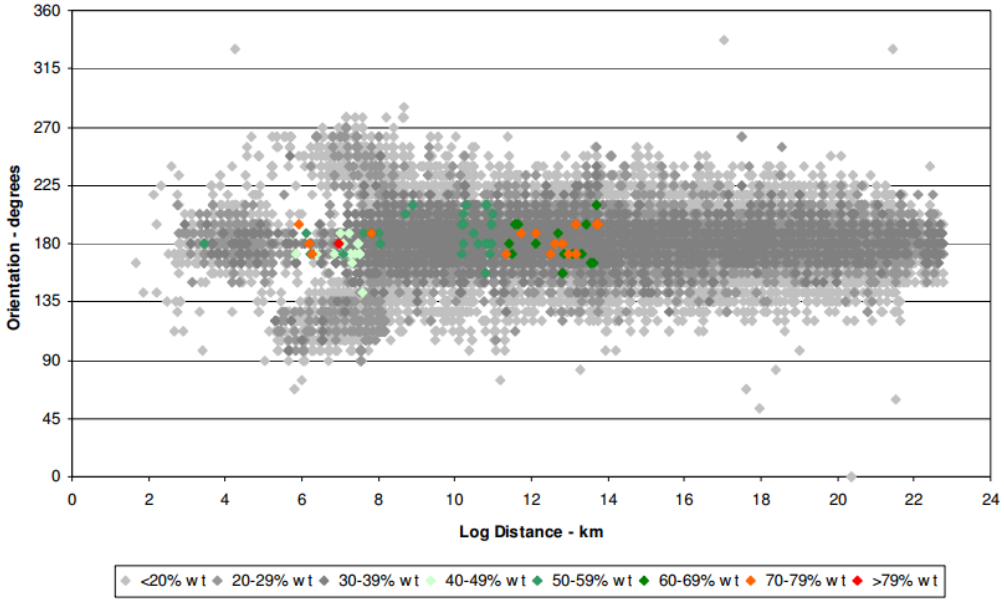


- Crude oil line, 7% water cut ; Constructed in 2004
- Inspected in 2007 by ILI
- 70% wt depth in 3 years!
- Pipeline failed…

ILI Pattern… Could we think MIC is a threat?

- Corrosion pitting in the BOL … characteristic pattern expected in a crude oil pipeline with a separate water phase… **CO_2 corrosion?**

ILI PATTERNS – MIC CASE STUDIES (3)…



- Crude oil line, 50% water cut ; Constructed in 2005
- Inspected in 2007 by ILI MFL
- 85% wt depth!
- Aggressive cleaned & written off in 2 years….

ILI Pattern… Could we think MIC is a threat?

…..Deep pits in uniform metal loss areas ……

CO_2/H_2S corrosion? Erosion at bottom? MIC?

MIC RECOGNITION FROM ILI?

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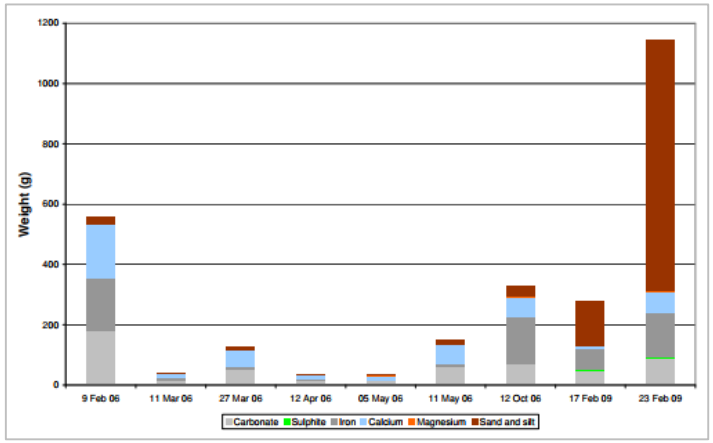
Sampling?

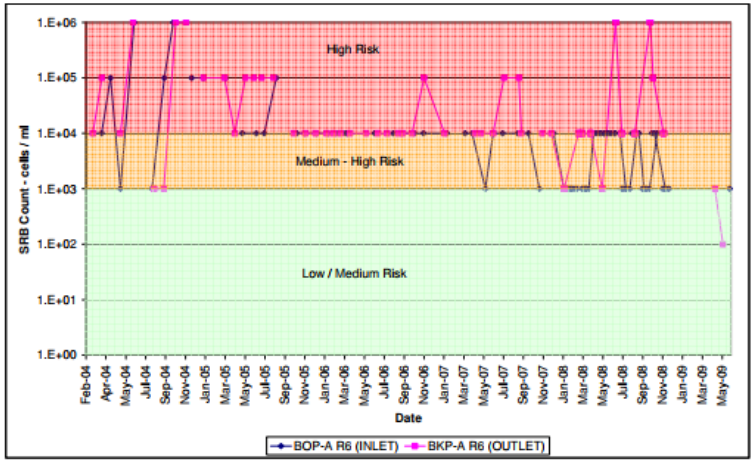
- Pigging… sand, sessile bacteria, iron sulphide …

Susceptibility modelling?

- Historical ops review…
- elevation profile, etc. ..

- **Holistic Threat review? What is the main driver?**
- **CO_2? H_2S? Bacteria? Water separation? Solid deposition? Flow characteristics?**





MIC MORPHOLOGIES VS ILI CAPABILITY…

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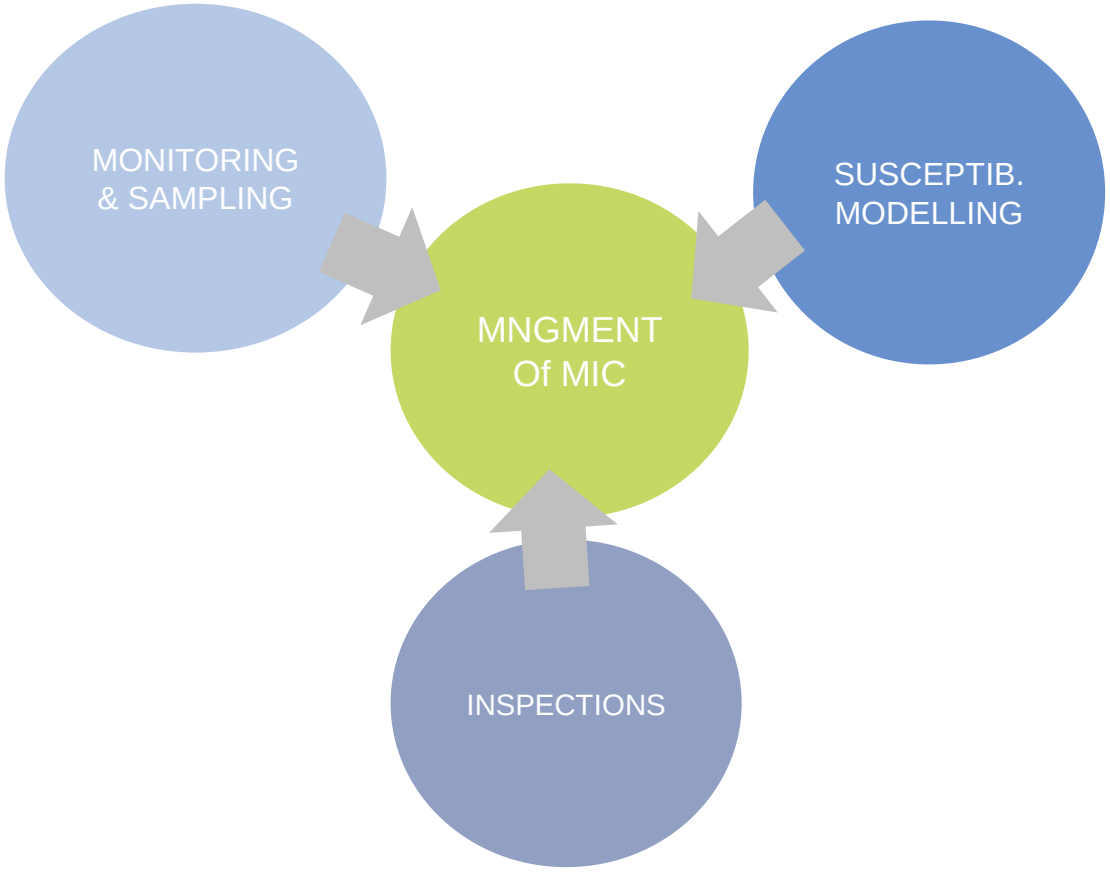
- **Can the sole use of ILI define whether MIC is present in my pipeline?**

NO!

… No Sole Gold-Standard Technology yet exists through which MIC can be reliably verified…

….MIC MANAGEMENT FRAMEWORK…



CONCLUSIONS

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- NO typical or unique MIC morphologies & metal loss patterns
- Traditional ILIs can detect most of MIC type defects…
- However… black swans…
  - Isolated pinholes <4mm
  - Pinholes in complex corrosion clusters, near GWs

- MFL-A Ultra has been developed to address pinholes and detailed resolution of complex corrosion geometry areas and near GWs
  - 3D imaging close to laser scan
  - Improved FFP assessments
  - Optimised intervention/management strategies

CONCLUSIONS

- Sole Use of ILI …
  - not enough to ID whether MIC is present & active
  - Not enough to manage MIC

- Requirement of a framework of different activities… sampling, susceptibity modelling, inspection to manage reliably MIC

THANK YOU FOR JOINING THIS PRESENTATION.

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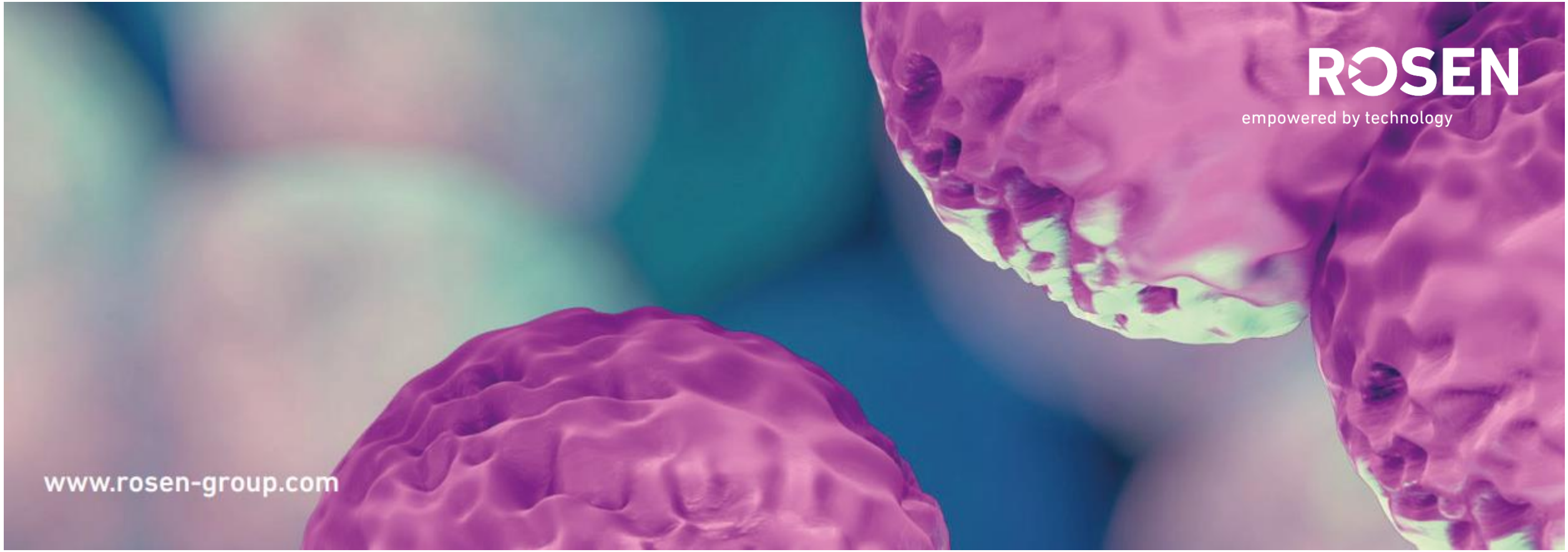

MANAGEMENT OF MIC

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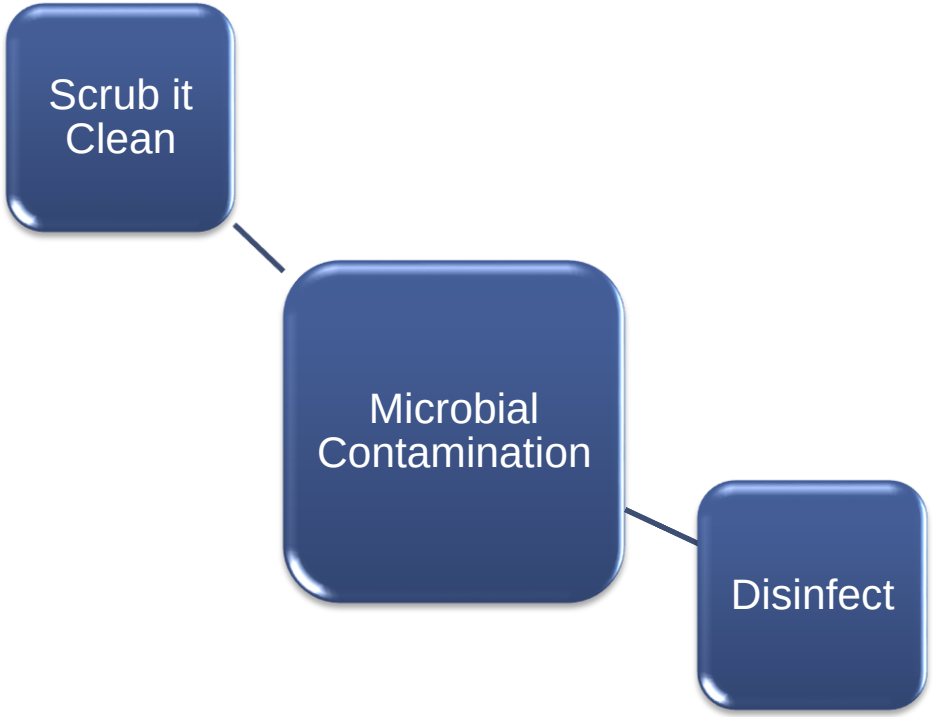
MITIGATION OF MIC IN PIPELINES



TIMELINE OF MIC

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1920s
MIC awareness as a known problem

1920s-40s
Study of microorganisms in oil production

1934
Desulfovibrio (SRB) genus implicated in corrosion of metals

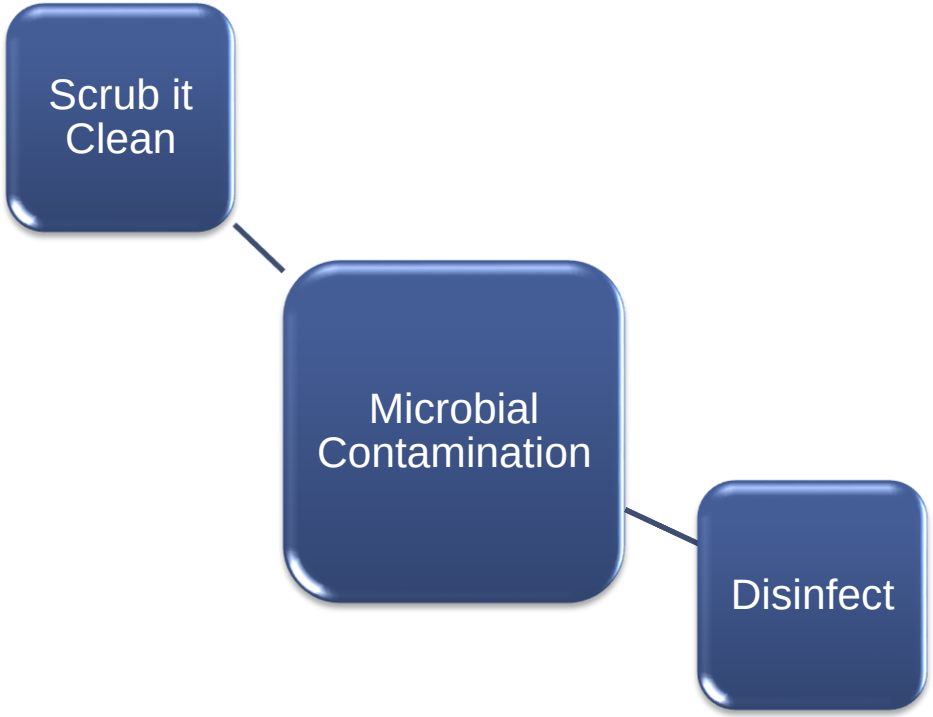
1940-50s
Depolarisation theory

1970s-80s
Biofilm – its importance and role in MIC

1980s
Increase in MIC research – focused on SRB

1990s
Advances in research techniques
Movement away from SRB

MITIGATION OF MIC IN PIPELINES



MANAGING MIC IN PIPELINES
IT'S JUST ANOTHER CORROSION THREAT

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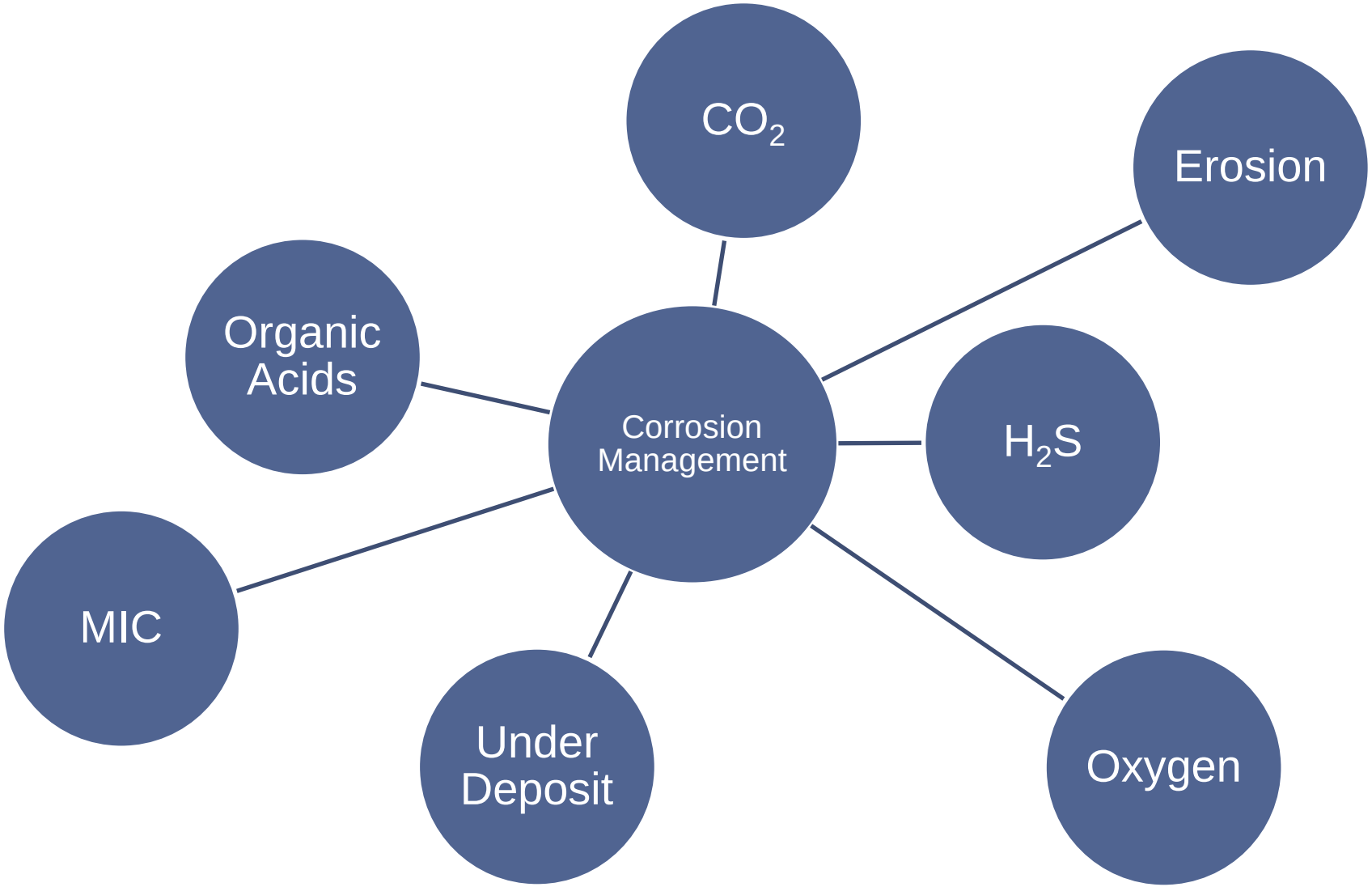
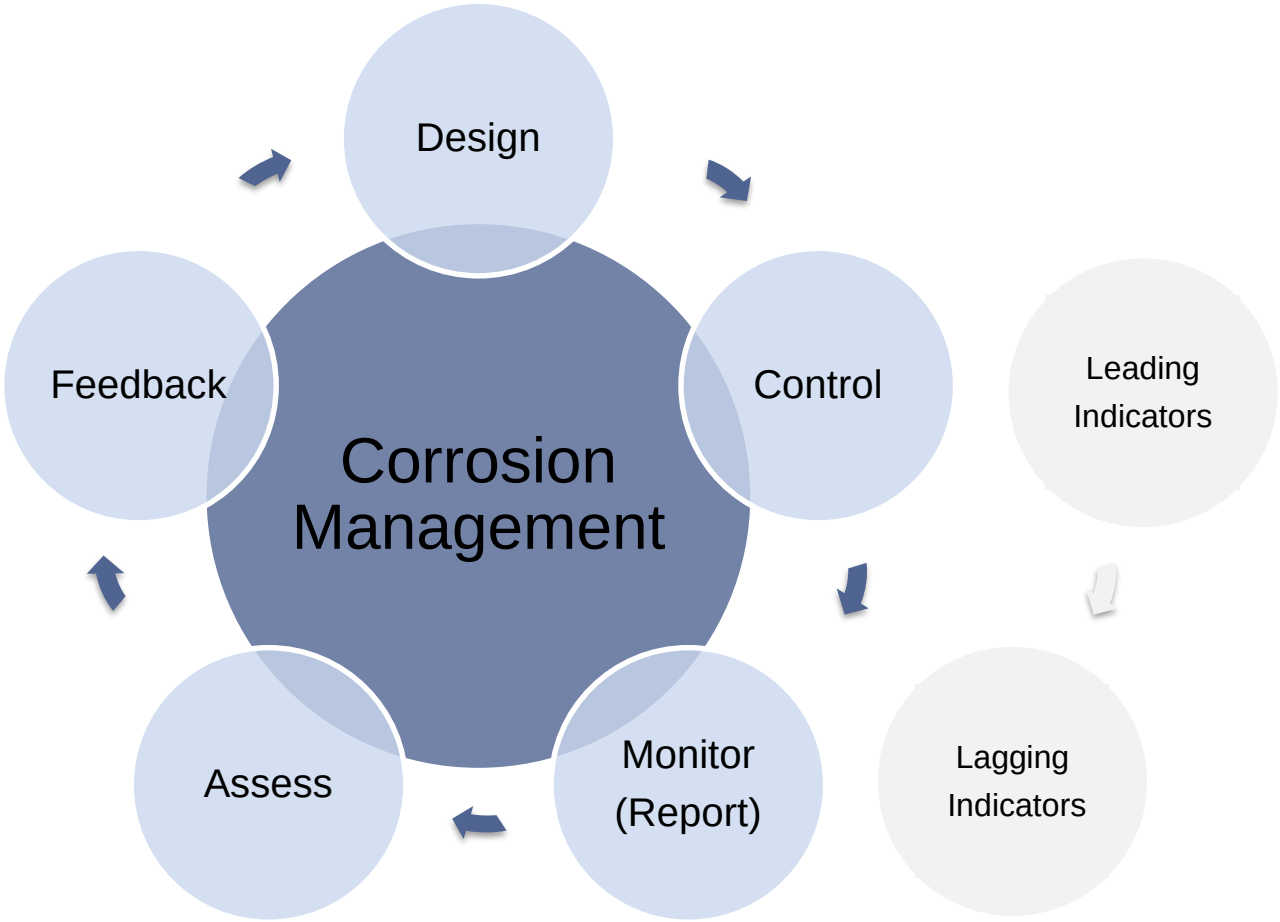


ELEMENTS OF THE CORROSION MANAGEMENT STRATEGY



CORROSION MANAGEMENT STRATEGY REQUIREMENTS

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Corrosion Management System

Balanced	*Non-biased to stakeholders, based on industrial standards & best practices (3rd party)*
Effective	*Process must be able to put in place the timely right course of action, must be both proactive & reactive.*
Economic	*time/resource consuming process will be frowned upon*
Transparent	*Auditable clear decision making processes, engineering judgment should be peer reviewed*
Living Process	*Active to allow for incorporation of new research, legislation etc.*
On Feedback Control	*Part of the 'active document' requirements, timing is key to an effective system.*
Data Management Control	*By nature will be data hungry, easily managed with data from various functions, increased accuracy and reduced conservative assessment.*

STEPS TO EFFECTIVE MIC MANAGEMENT

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Step 1: Designing for MIC

- Make pipeline piggable
- Assess MIC threat – susceptibility modelling
- Abiotic & biotic parameters – modelled process data
- Preventive corrosion control engineering – materials selection/process control
- Early return on biofilm & inner surface condition – bioprobes/flush coupons/side streams
- Pre-Commissioning plan – start clean
- Baseline ILI – know your starting point
- Devise protocols for MIC controls, sampling, extraction, analysis and assessment.

Step 2: Control and Implementation

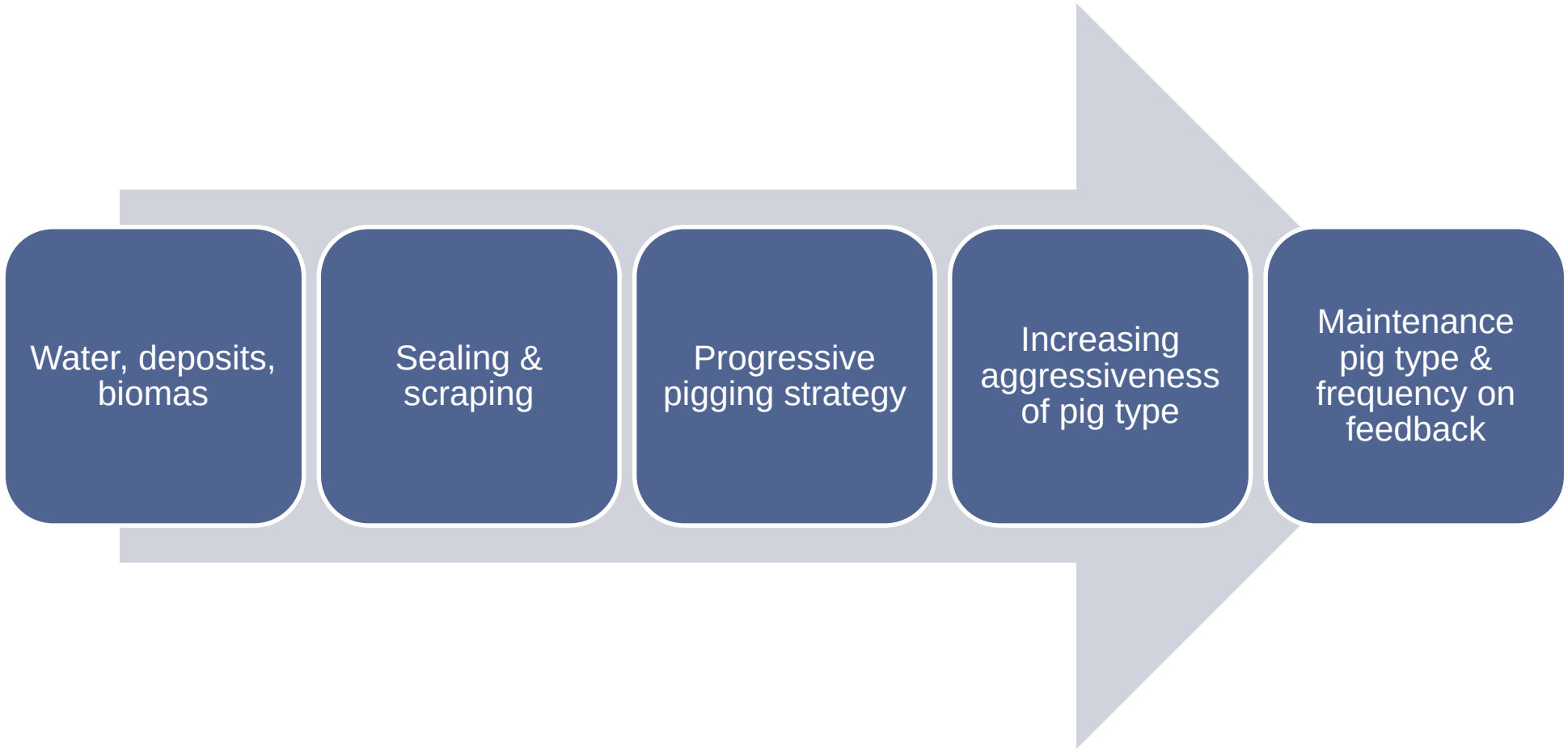
- MIC control systems in place – pigging, biocide & monitoring facilities
- Type of cleaning pig and initial frequency determined from flow modelling
- Biocide type & mode of deployment determined – injection/batch
- Simulation testing of controls for initial optimization – max biocide contact time
- Everything to set protocols for reproducibility
- Implementation according to strategy

Step 3: Monitoring and Assessment

- Collect microbial, corrosion & operational information according to monitoring protocols
- Determine mitigation effectiveness – KPI management – need return of system corrosion rates via ILI or on-line mode.
- Determine relationship between sessile & planktonic numbers
- Re-evaluate susceptibility assessment
- Data trending for confidence – feedback to change management
- Change frequencies for optimization of early warning based on MIC risk level
- Re-set cleaning frequency

MIC KPI?

CLEANING FOR MIC



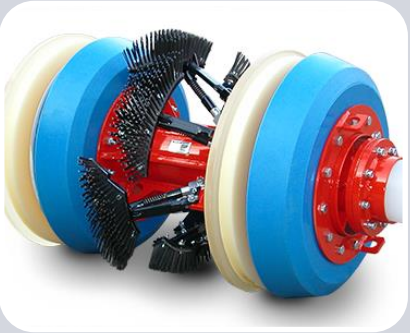
TYPES OF CLEANING TOOLS

Sphere

Foam

Solid Cast

Steel Mandrel



Wires
Cups
Discs
Smart

CHALLENGES WITH MIC

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- A unified predictive model for MIC susceptibility, risk, corrosion rate and location within pipelines
- Protocols for sampling and analysis of a pipeline system to enable the use of global data
- An EU program of collaboration on the problem of MIC

PIPELINE INTEGRITY & MIC
ROSEN GLOBAL FRAMEWORK

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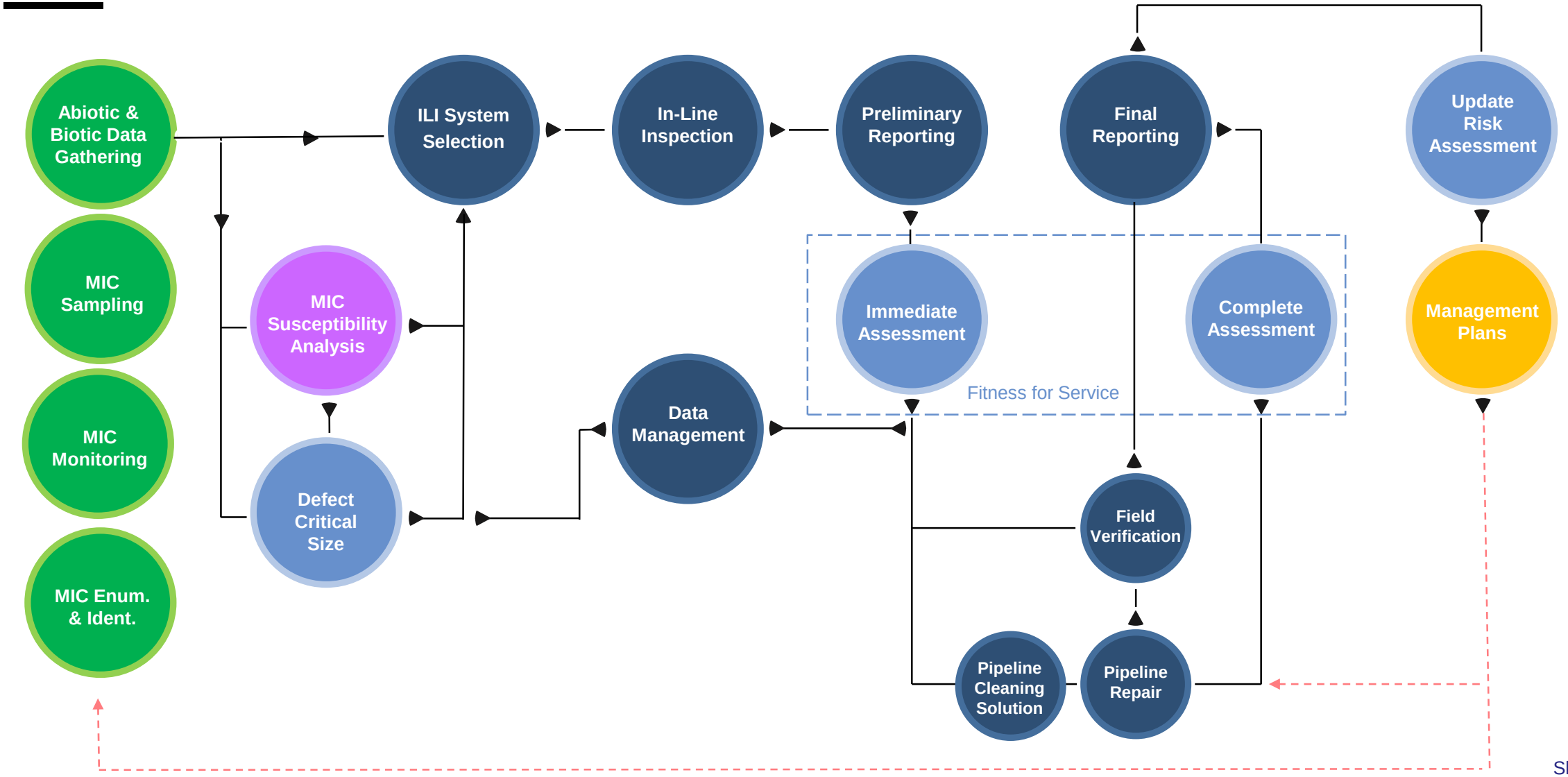

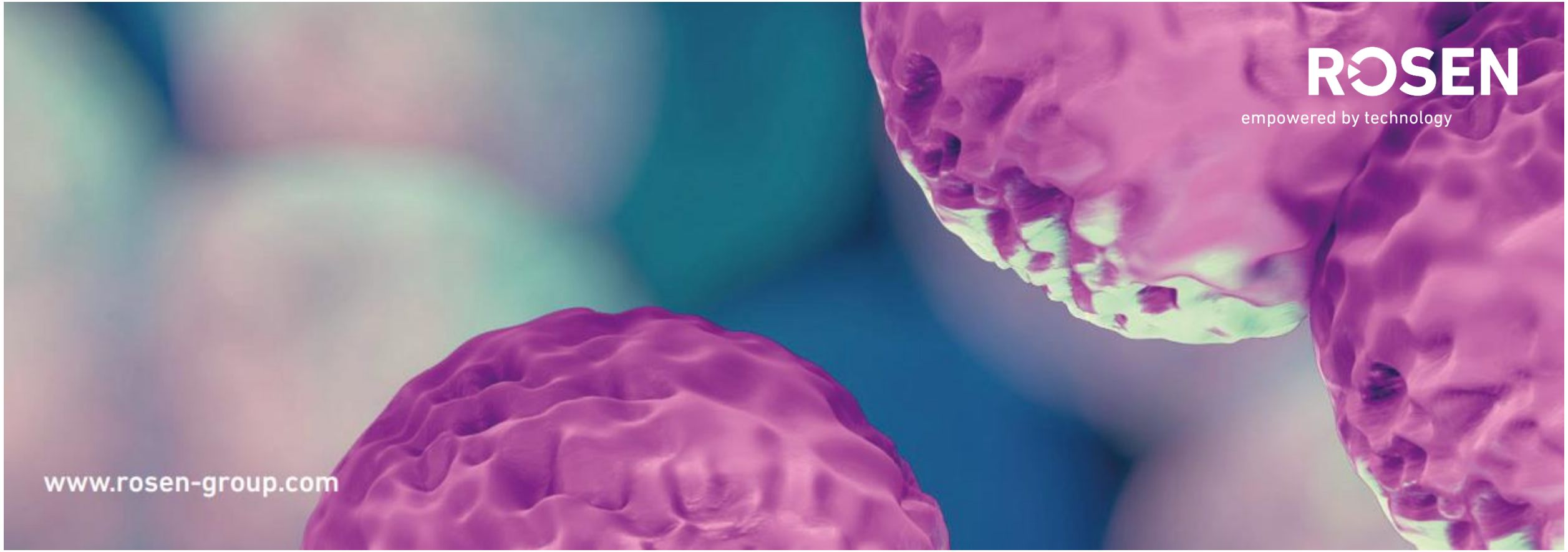

THANK YOU

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