Appendix 1

List of participants

NAME	SURNAME	COMPANY	COUNTRY
Arslanov	Marat	KBR	RUSSIA
Atzeri	Giuseppe	SARLUX	ITALY
Baak	Michael	Borealis Polyolefine GmbH	AUSTRIA
Bart	Martens	PPG Protective & Marine Coatings	UK
Bateman	Colin	Integrated Global Services	UK
Bond	Stuart	Nace Europe	UK
Bour Beucler	Valerie	Nalco Champion	FRANCE
Castells	Adolfo	Oerlikon metco	USA
Cheney	Justin	Oerlikon Metco	USA
Chernyavskiy	Petr	KBR	RUSSIA
Claesen	Chris J	Nalco Champion	BELGIUM
Corradini	Raffaele	Techint Engineering Construction	ITALY
Daly	Simon	Hempel UK Ltd	UK
De Landtsheer	Gino	Borealis	BELGIUM
Dodelin	Laure	Total Refining & Chemicals	FRANCE
Eronen	Ville	Oerlikon Metco Finland	FINLAND
Faraone	Nicola	Voestalpine Böhler Welding GmbH	ITALY
Farina	Carlo	CEFIT Corrosion Consultant	ITALY
Gazrati	Imran	D.V.Sokolskiy Institute of Fuel, Catalysis and Electroche	KAZAKHSTAN
Geraskin	Vitaly	Integrated Global Services	CZECH REPUBLIC
Gregoire	Vincent	Equinor	NORWAY
Hairer	Florian	Linde, Engineering Division	GERMANY
Haskett	David	Subterandt	SPAIN
Hermse	Chretien	Shell Moerdijk	NETHERLANDS
Hofmeister	Martin	Bayernoil Raffineriegesellschaft mbH	GERMANY
Houlle	Patrice	Patrice Houlle Corrosion Service - MTI	FRANCE
Höwing	Jonas	Sandvik	SWESEN
Iavorschi	Mihail-Gustav	OMV Refining & Marketing GmbH	AUSTRIA
Kadyrzhanovna	Altynai	D.V.Sokolskiy Institute of Fuel, Catalysis and Electroche	KAZAKHSTAN
Koller	Swen	Holborn Europa Raffinerie GMBH	GERMANY
Kroth	Matthias	OMV Deutschland Operations GmbH & Co. KG	GERMANY
Kroth	Matthias	OMV Refining & Marketing GmbH	AUSTRIA
Kuhn	Michael	PPG Protective & Marine Coatings	UK
Kus	Slawomir	Honeywell	UK
Leone	Antonino	Eni	ITALY
Links	Jan	Dow Benelux B.V.	NETHERLANDS
Low	Philip	Zerust Oil andGas	SPAIN
Maffert	Joerg	Dillinger Huttenwerke	GERMANY
Magel	Chis	PPG Protective & Marine Coatings	UK
Makhoul	Roger	Spraying Systems MENA Co	UNITED ARAB EMIRATES
Mo	Yeqiang	Shenzhen University	CHINA
Monnot	Martin	Industeel	FRANCE
Nail	Kenzin	D.V.Sokolskiy Institute of Fuel, Catalysis and Electroche	KAZAKHSTAN
Nursultan	Nurgaziev	D.V.Sokolskiy Institute of Fuel, Catalysis and Electroche	KAZAKHSTAN
Onodera	Yoichi	Mitsui & Co Ltd	JAPAN
Pålsson	Namurata	RISE	SWEDEN
Pessiridi-Blagikh	Yana	D.V.Sokolskiy Institute of Fuel, Catalysis and Electroche	KAZAKHSTAN
Ropital	François	IFP Energies nouvelles	FRANCE
Schempp	Philipp	Shell Deutschland Oil GmbH	GERMANY
Shapcott	Stefen	Johnson Matthey Process Technologies	UK
Sharma	Prafull	Corrosion RADAR	UK
Soundararajan	Sudharsanan	ADNOC-Refining	UNITED ARAB EMIRATES
Suardi	Edoardo	SARLUX	ITALY
Surbled	Antoine	A.S – CORR CONSULT	FRANCE
Suzuki	Yuhei	Nippon Steel Europe GmbH	GERMANY
Talbot	Freddie	CorrosionRADAR	UK
Ulm	Philipp	Bayernoil Raffineriegesellschaft mbH	GERMANY
Van Dooren	Piet	Borealis	BELGIUM
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Vanacore	Alessandro	Donegani Anticorrosione	ITALY
Vassileva	Vassilka	OMV Refining & Marketing GmbH	AUSTRIA
Vinogradov	Roman	KBR	RUSSIA
Vosecký	Martin	Nalco Champion	CZECH REPUBLIC
Wijnants	Geert Henk	Stork	NETHERLANDS
Wold	Kjell	Emerson	NORWAY
Zhanabayev	Daulethan	D.V.Sokolskiy Institute of Fuel, Catalysis and Electroche	KAZAKHSTAN
Zlatnik	Ivan	MITSUI & Co Deutschland	CZECH REPUBLIC

Appendix 2

EFC WP15 Activities

(Francois Ropital)

EFC Working Party 15 « Corrosion in Refinery and Petrochemistry » Activities

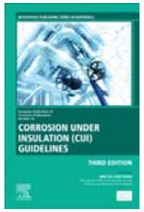
Chairman: Francois Ropital Deputy Chairman: Johan Van Roij

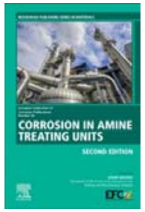
Information Exchange – Forum for Technology
Sharing of refinery materials /corrosion experiences by operating company representatives (ie corrosion atlas).
Sharing materials/ corrosion/ protection/ monitoring information by providers

Eurocorr Conferences : organization of refinery session and joint session with other WPs (2021 Virtual, 2022 Berlin-Germany, 2023 Brussels-Belgium)

WP Meetings
One WP 15 working party meeting in Spring,
One meeting at Eurocorr in September in conjunction with the conference,

Publications - Guidelines





Web site : https://efcweb.org/Scientific+Groups/WP15_+Corrosion+in+the+Refinery+and+Petrochemistry+Industry-p-38.html

List of the WP15 spring meetings :

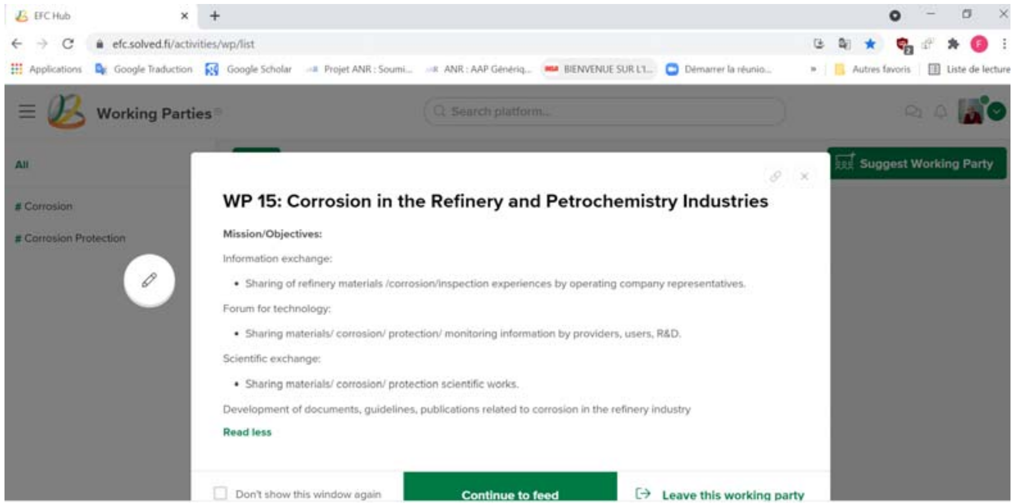
10 April 2003	Pernis - NL (Shell)
8-9 March 2004	Milan -Italy (ENI)
17-18 March 2005	Trondheim- Norway (Statoil)
31 March 2006	Porto Maghera - Italy (ENI)
26 April 2007	Paris - France (Total)
15 April 2008	Leiden -NL (Nalco)
23 April 2009	Vienna - Austria (Borealis)
22 June 2010	Budapest - Hungary (MOL)
14 April 2011	Paris - France (EFC Head offices)
26 April 2012	Amsterdam - NL (Shell)
9 April 2013	Paris - France (Total)
8 April 2014	Mechelen - Belgium (Borealis)
14 April 2015	Leiden -NL (Nalco)
26 April 2016	Paris - France (Total)
13 April 2017	Frankfurt - Germany (EFC Head offices)
3 May 2018	Dalmine - Italy (Tenaris)
10 April 2019	Roma - Italy (Rina CSM)
23 March 2021	Zoom meeting

Publications from WP15 – Forum Platform

•EFC Guideline n° 55 **Corrosion Under Insulation** Editor: Gino de Landtsheer
The 3rd revision is now available

https://www.elsevier.com/books/corrosion-under-insulation-cui-guidelines/de-landtsheer/978-0-12-823332-0

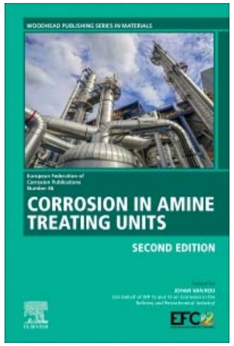
A Web forum platform on the EFC Hub platform on CUI questions and to share documents is under construction
https://efc.solved.fi/activities/wp/list



Publications from WP15

•EFC Guideline n° 46 revision on corrosion in amine units Editor: Johan van Roij *is now available*

https://www.elsevier.com/books/corrosion-in-amine-treating-units/van-roij/978-0-323-91549-6



• Best practice guideline on corrosion in sea water cooling systems (joint document WP9 Marine Corrosion and WP15)

In progress by a task force : first version in September 2021

Thank you to all the contributors for their work

Joining EFC WP15 activities

If you are not on the list of WP15 members and you want to join you can

- Fill the EFC Friend form https://efcweb.org/friendsform.html

- Or send an email to francois.ropital@ifpen.fr

EFC Web site :https://efcweb.org/

Appendix 3

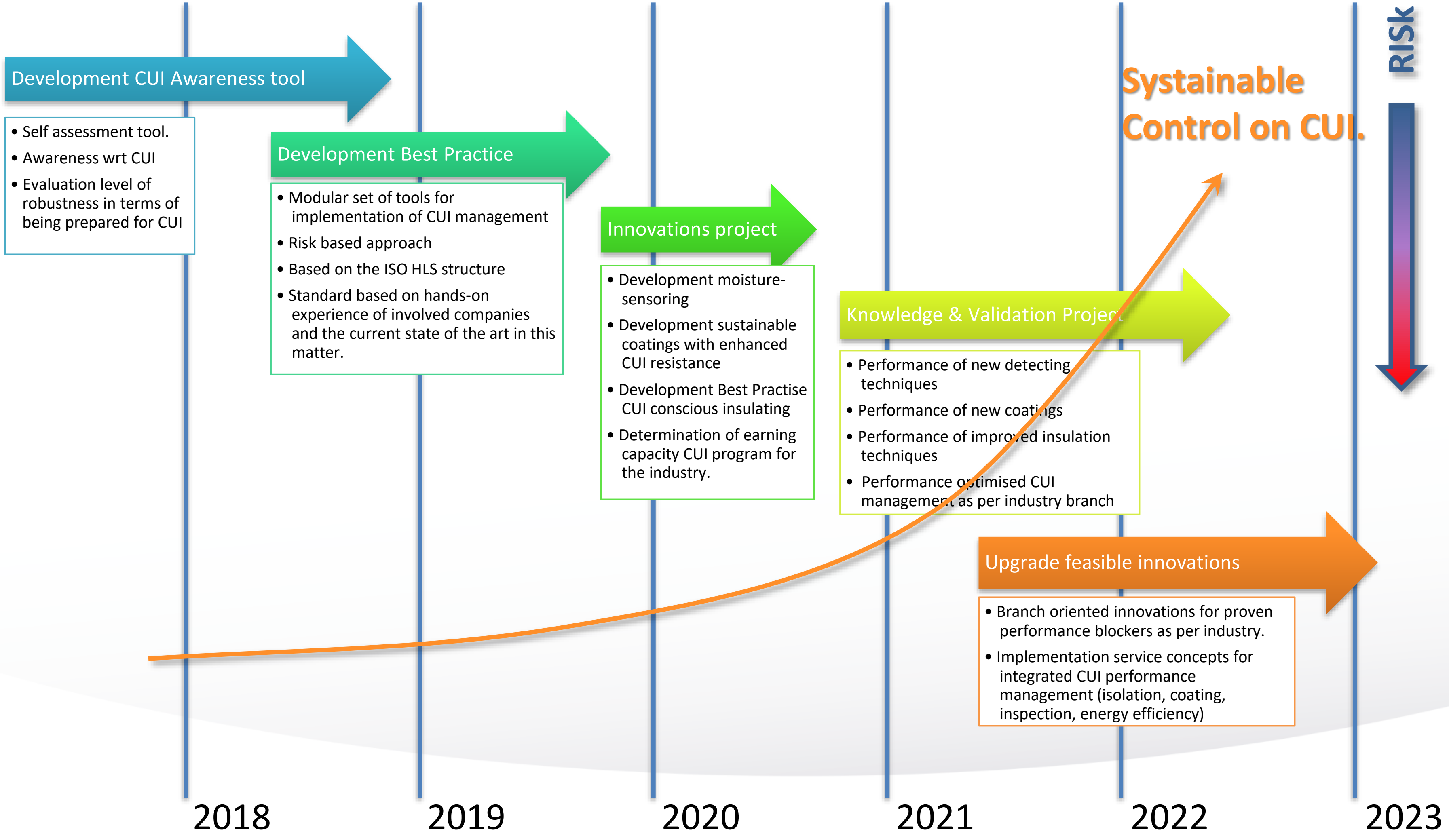
Corrosion under insulation in asset management perspectives

(Gerth Henk Wijnants)

Corrosion Under Insulation
in Asset Management perspective

Geert Henk Wijnants
Principal Consultant, STORK Asset Management Technology

Corrosion Under Insulation *roadmap*



Call for Action / Business Driver

- Prevention is better than correction.
- Save on failure costs.
- Investing in a cost-effective approach from TCO.
- Recognisability from management structure
- Preventing "trial and error" approach

CUI solution:

- Modular approach based on maintaining what is good, improving what can be improved.
- Using generally proven concepts with regard to predicting corrosion, assessing damage, determining risk, estimating lifespan, controlling costs.
- Transparency through independent approach from WCM; a supplier-independent concept.
- With the involvement of KINT, ION, VNCI, RVO, SDN

Business model:

- Risk-oriented, so investment in those areas where is yields best profits.
- Taking into account of continuing those concepts which are already doing well.
- Improve together by using each others individual experiences for the better good.

(Potential) partners:

- Asset-owners from "BRZO" sector
- Isolation and coating industry
- Inspection- and service suppliers

WORLD CLASS MAINTENANCE

Corrosion Under Insulation

Status quo:

- Best practise CUI management.
- Tools for implementation (XLSX; PPTX)
- Gap analysis for optimisation

Modular setup. Elements:

- ➢Standardized Risk Assessment Method
- ➢Decision model for coating lifetime with risk(t)
- ➢Corrosion rate CUI over time with valuation in risk
- ➢Assessment of the condition of insulation, effect on risk
- ➢(Cost-)Effectiveness of NDT, influence on “grip on risk”
- ➢Awareness presentation regarding impact CUI management program with costs/benefits.
- ➢The best practice description according to “ISO high level structure” for RBI CUI.

WORLD CLASS MAINTENANCE

Next steps:

Innovation along the following tracks:

- Develop decision tool based on inspection costs
- Standardization in terms of condition determination
- Building a database with CUI related incidents
- Establishing a coating monitoring program
- Development of a cost-effective moisture monitoring program
- Wider application of the CINI standard.

Connection with your track?

Boarding / steering?

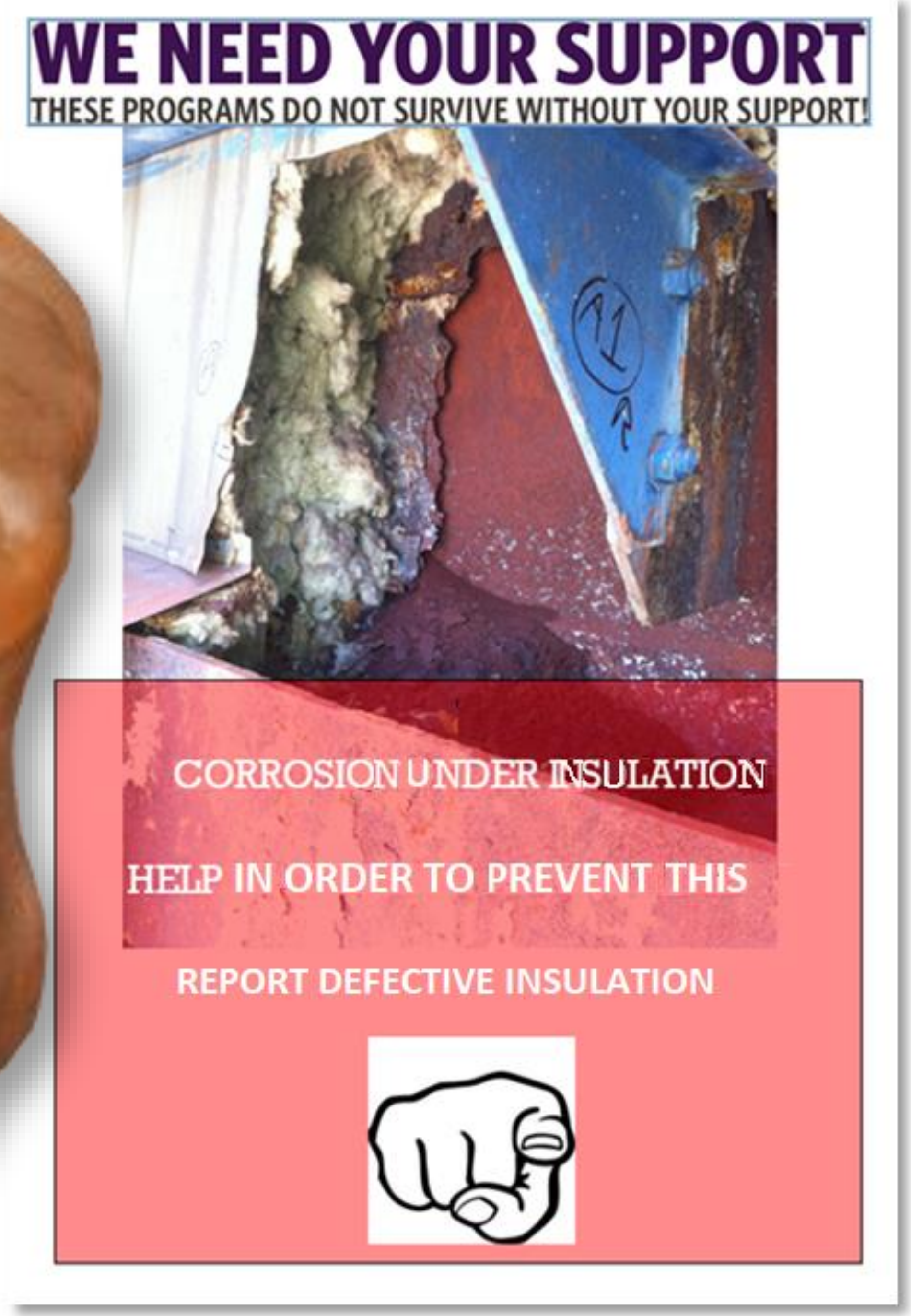
Directing group – meeting once every 2-3 months.

Project team – half day / 2 weeks.

Focus on concrete results to be achieved.

Working on the basis of work processes that are in line with "what needs to be done".

So not "thinking and acting for …" but "together with & by".



WORLD CLASS MAINTENANCE

Appendix 4

Minimising CUI using insulation coatings: advantages and disadvantages over conventional insulation including the use of a novel NDT technique for detecting CUI

(Simon Daly)

Minimising CUI using insulation coatings: Advantages and disadvantages over conventional insulation including the use of a novel NDT technique for detecting CUI

Simon Daly - Hempel A/S
sida@hempel.com

5 key takeaways

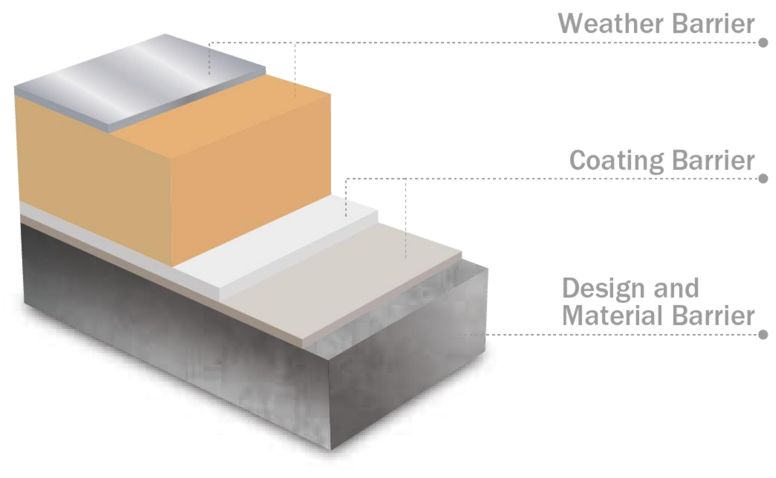
- Replacing insulation where possible reduces CUI risk
- Insulation coatings highly effective for personnel protection
- Newer materials can serve other insulation purposes
- Seamless, non-porous materials reduce CUI risk
- Sub-TeraHertz technology effective at detecting CUI beneath insulation coatings

Why is Corrosion Under Insulation (CUI) such a challenge?

- Hidden
- Unpredictable
- Costly to find and fix
- Dependent upon environment (water source)
- Consumes lots of management time
- High consequence – major safety event

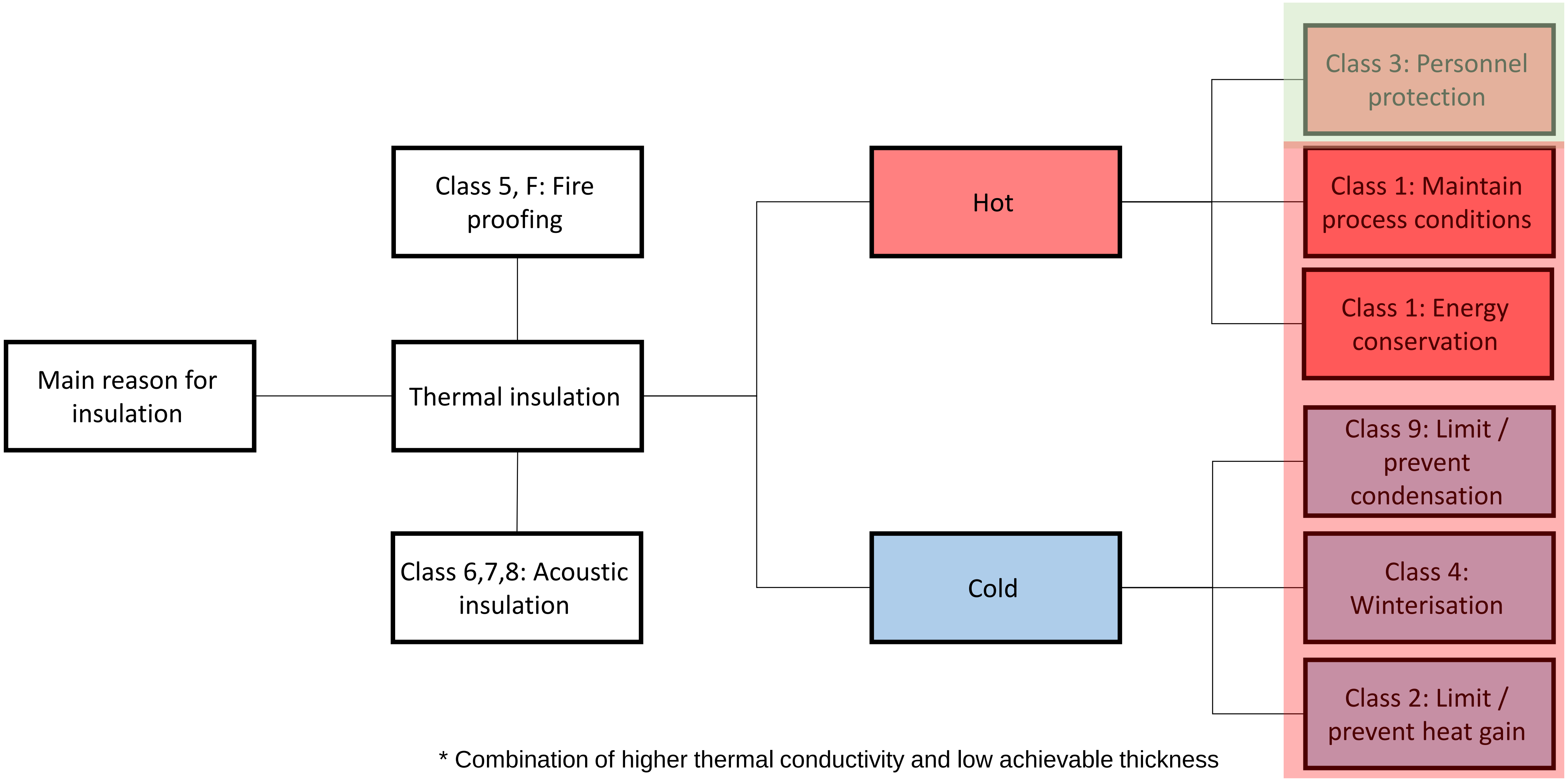
Ways to mitigate Corrosion Under Insulation (CUI) risk

Mitigation	Construction materials	Insulation / cladding	Coating	Design
General visual inspection (GVI)		Limited impact		
Close visual inspection (CVI) (outside cladding)		Some impact		
Insulation removal + CVI		Good impact	Good impact	
Coating refurbishment		Good impact	V. good impact	
Coating refurbishment (repair only)			Good impact	
Repair / replacement of insulation		Good impact		
Non destructive testing				
Permanent removal of insulation	V. good impact	V. good impact	V. good impact	V. good impact



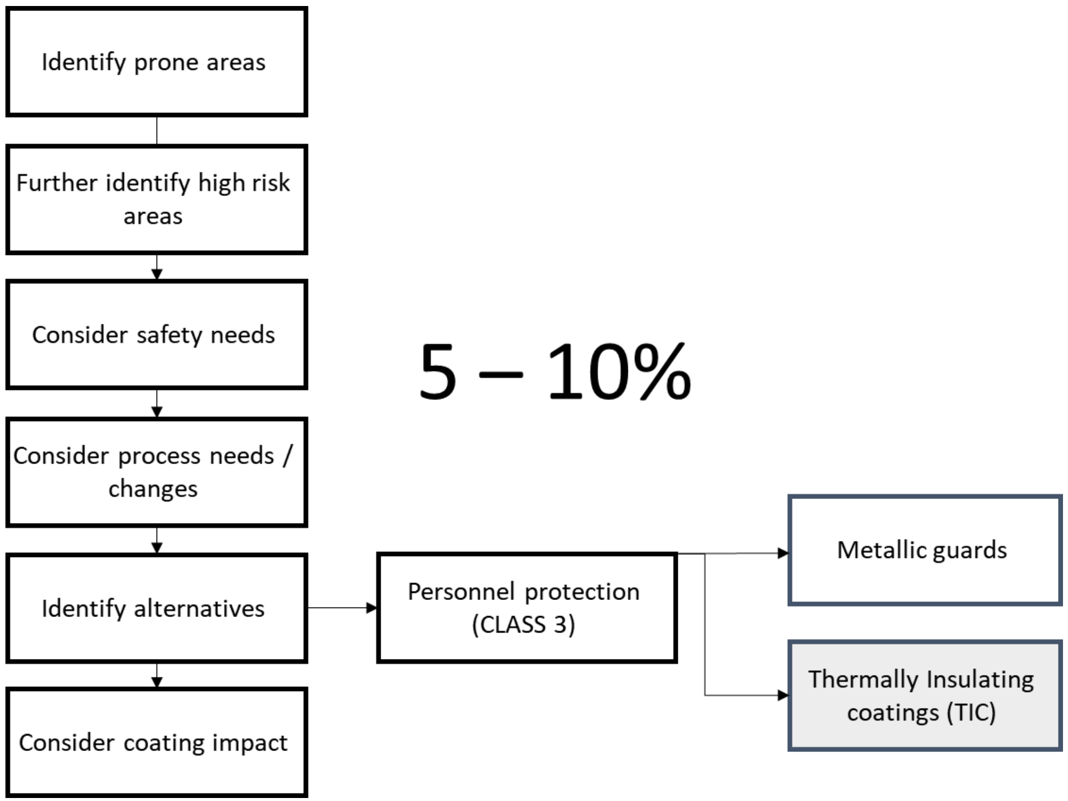
- Limited impact
- Some impact
- Good impact
- V. good impact

Potential uses of insulation divided into classes (IOGP S-738)



* Combination of higher thermal conductivity and low achievable thickness

Considerations for insulation removal



- Likely replacement with insulation coatings
  - Fireproofing **LOW**
  - Acoustic **LOW**
  - Winterisation **LOW**
  - Energy conservation **LOW**
  - Process control **MEDIUM**
  - Condensation control **MEDIUM**
  - Personnel protection **HIGH**

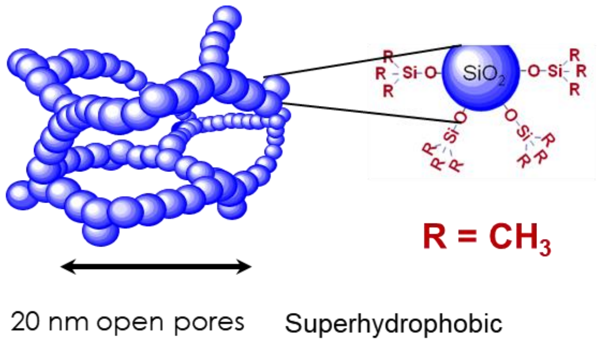
Use of personnel protection guards

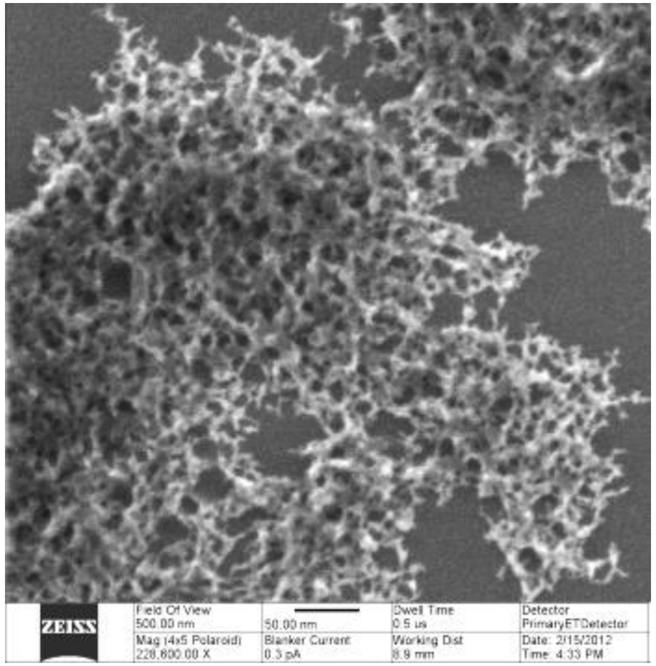
- Potential savings
  - 100% cost of CUI replacement
  - 10 - 20% initial costs on insulation
  - Future CUI inspection costs
- Carbon or stainless steel
- Mesh aperture depends on standoff distance
- Installed around platforms, access ways, stairways, ladders etc.
- Consider pipe paint scheme

Image acknowledgement: Piping technology & products Inc.

Thermal Insulation coatings (TICs)

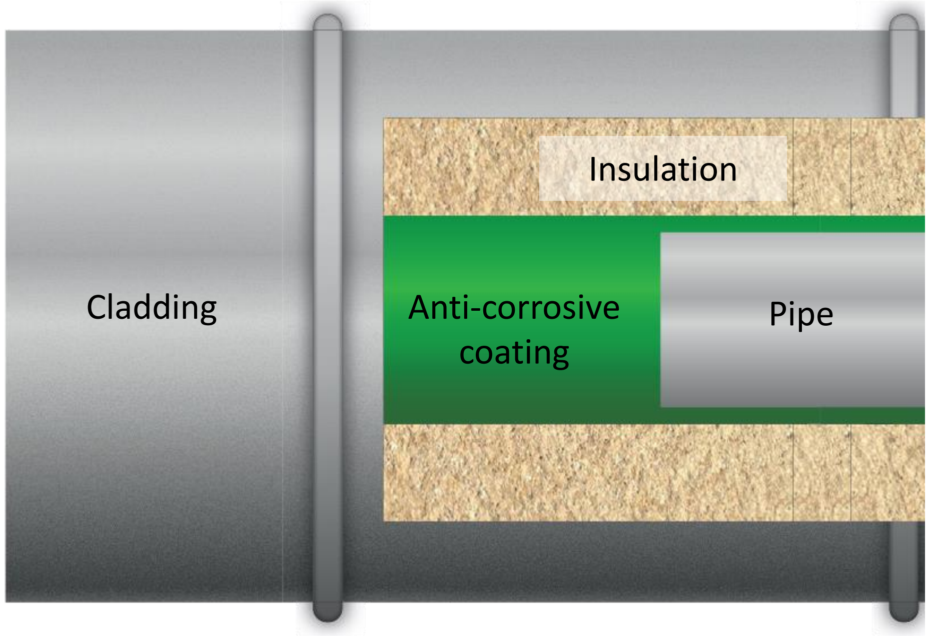
- Insulation coating typically consists of
  - Binder
  - Insulating powder
  - Additives
- May be reactive (2-K) or physically drying (1-K)
- Wide variety
  - Generic types
  - Thermal properties
  - Application usefulness



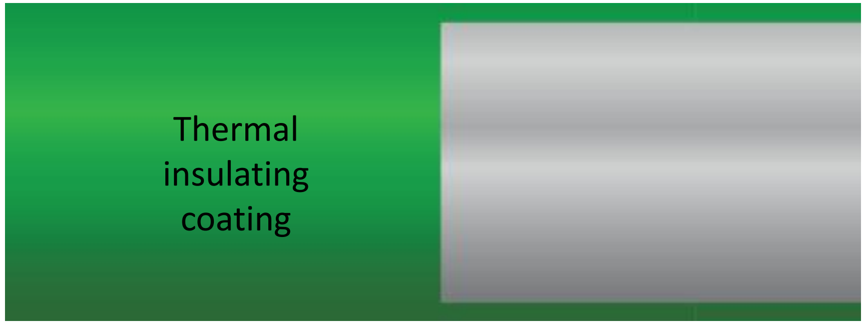


Helium ion microscopy of Aerogel powder.

Providing personnel protection in a different way



- Reduces surface temperature due to low thermal conductivity of insulation material



- Reduces heat transfer to skin
- Limited insulation value due to thickness
- Focus has been on Class 3

- Newer materials available
  - Higher film build
  - Improved thermal properties

Providing personnel protection in a different way

- Insulation coating reduces heat transfer into skin
- ASTM C1055 defines burn 'contact' conditions
  - Time for contact — Industrial, 5 s
  - Injury level — Threshold B, reversible epidermal injury (58° C)
- Surface temperature 60° C often substituted
- May lead to over-specification

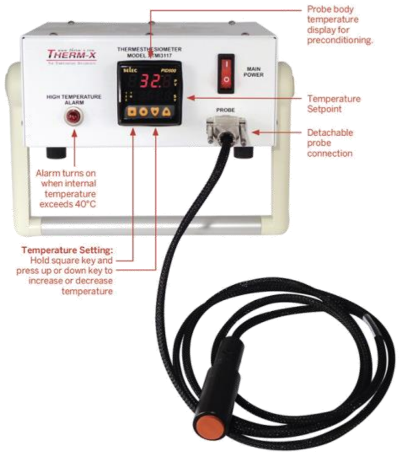
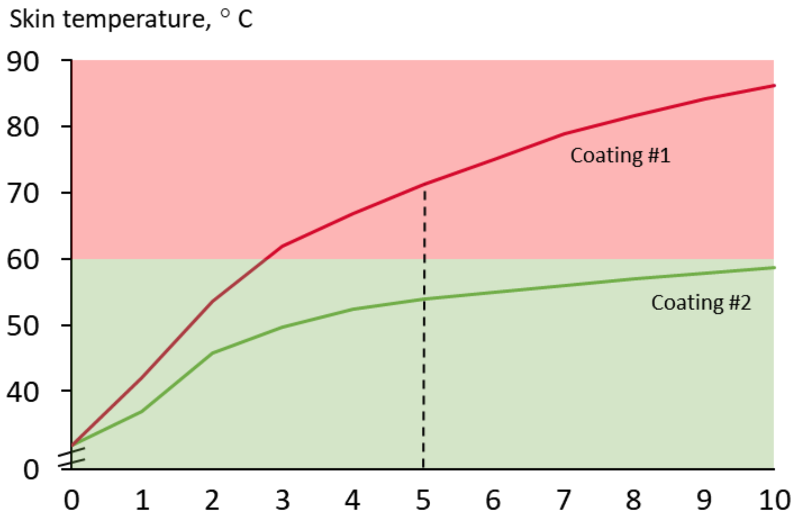
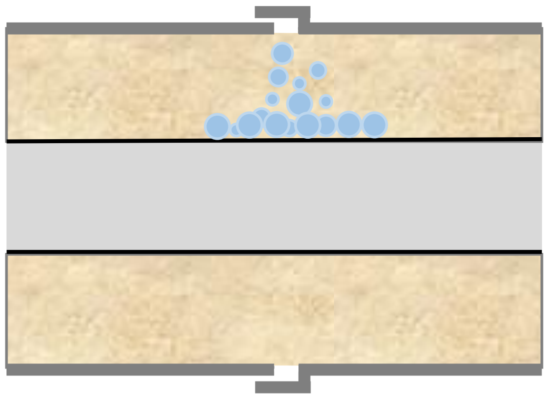
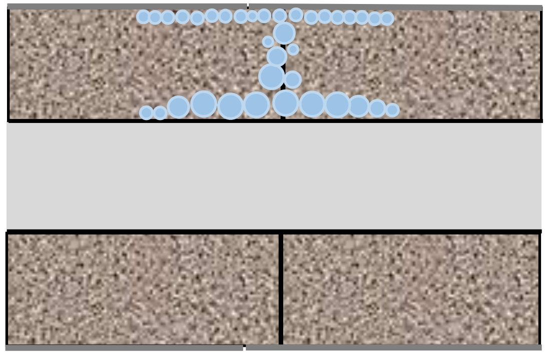


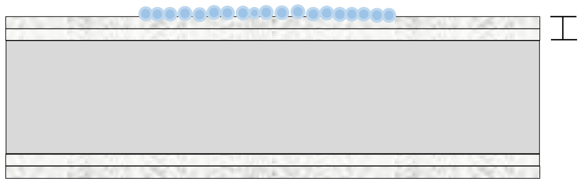
Image acknowledgement: Therm-X, Ca, USA



Combining personnel and corrosion protection







- TIC, Seamless eliminates water ingress
- Bonded to substrate
- Via primer, single layer anti-corrosive
- Top-coated

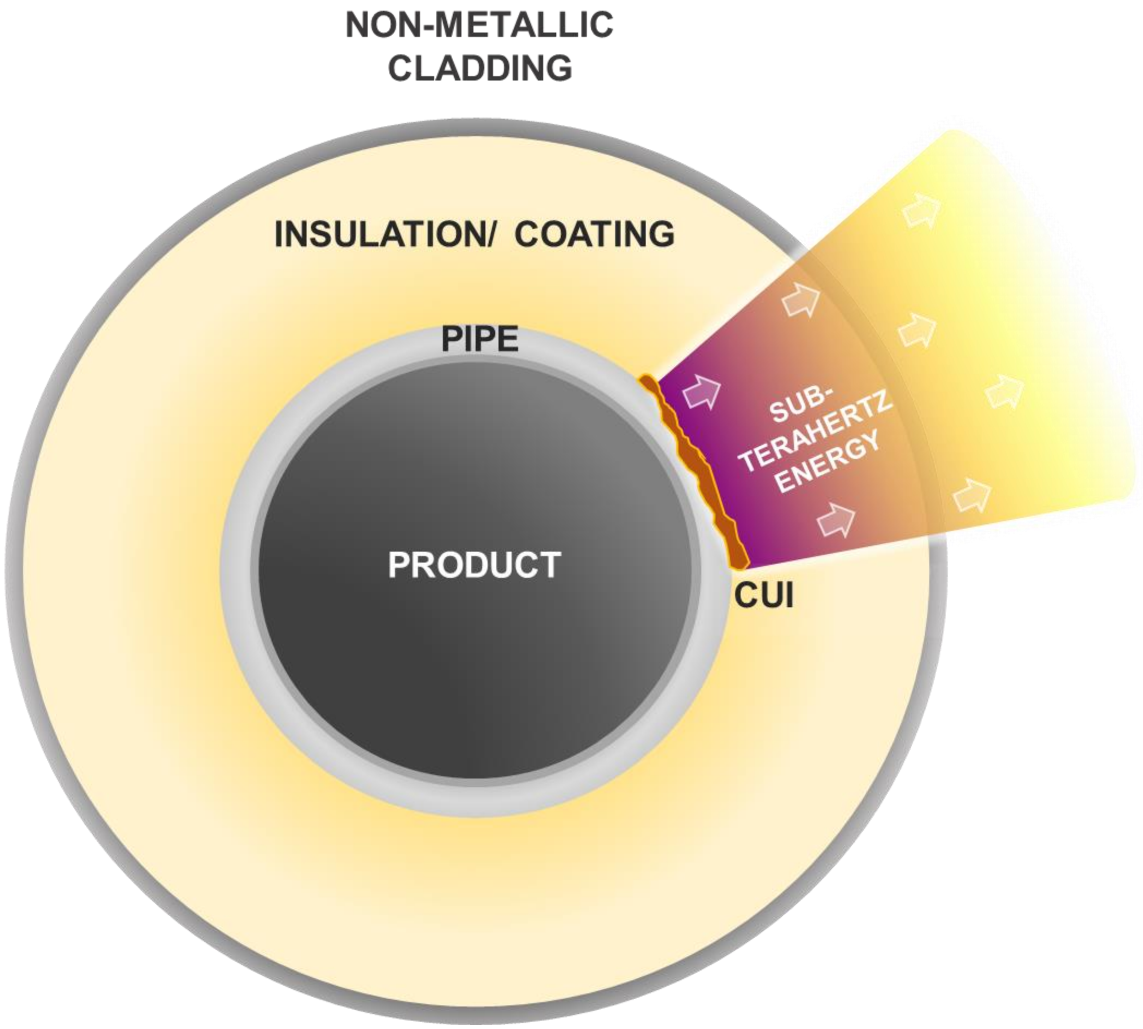
New insulation coatings can be applied at significantly higher total film thicknesses approaching conventional insulation

Introducing SubTera

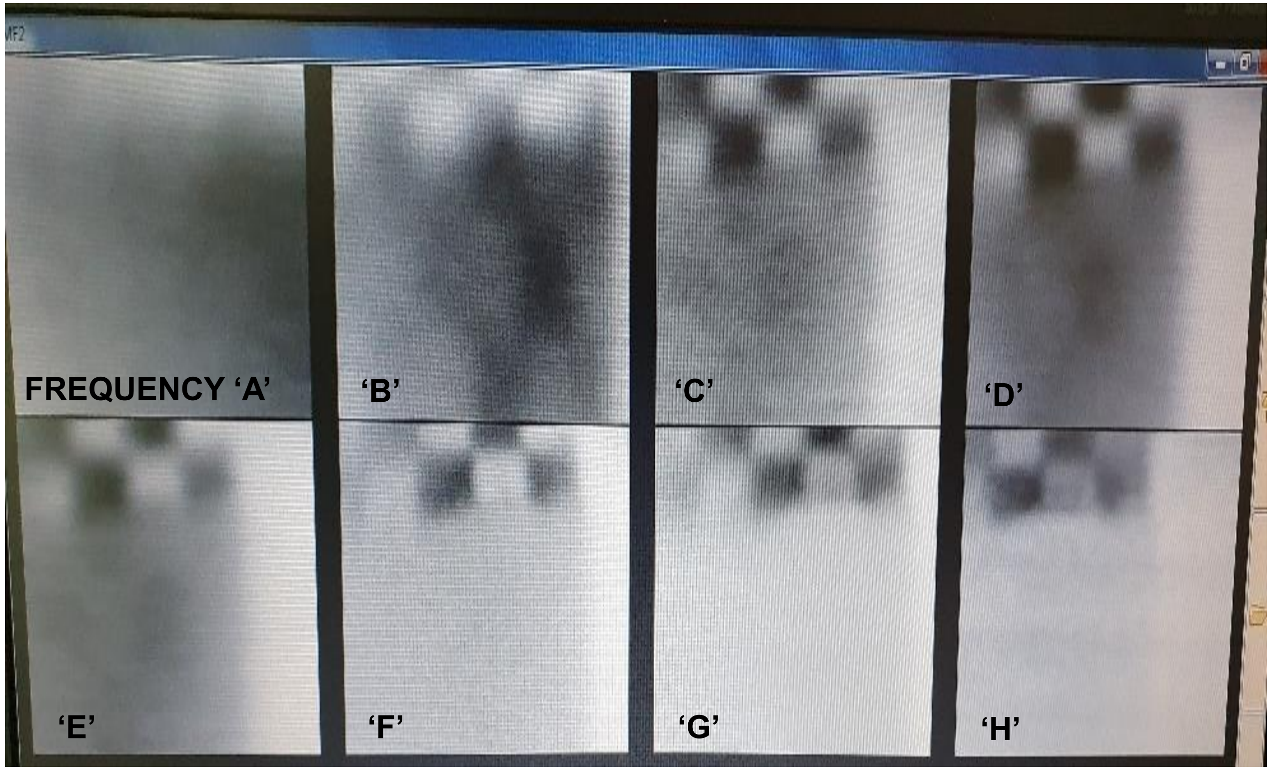
- UK NDT start-up focussing on
- Real time CUI detection
- Sub-TeraHertz sensing technology
- Prototype trial and evaluation stage

Introducing sub-TeraHertz technology

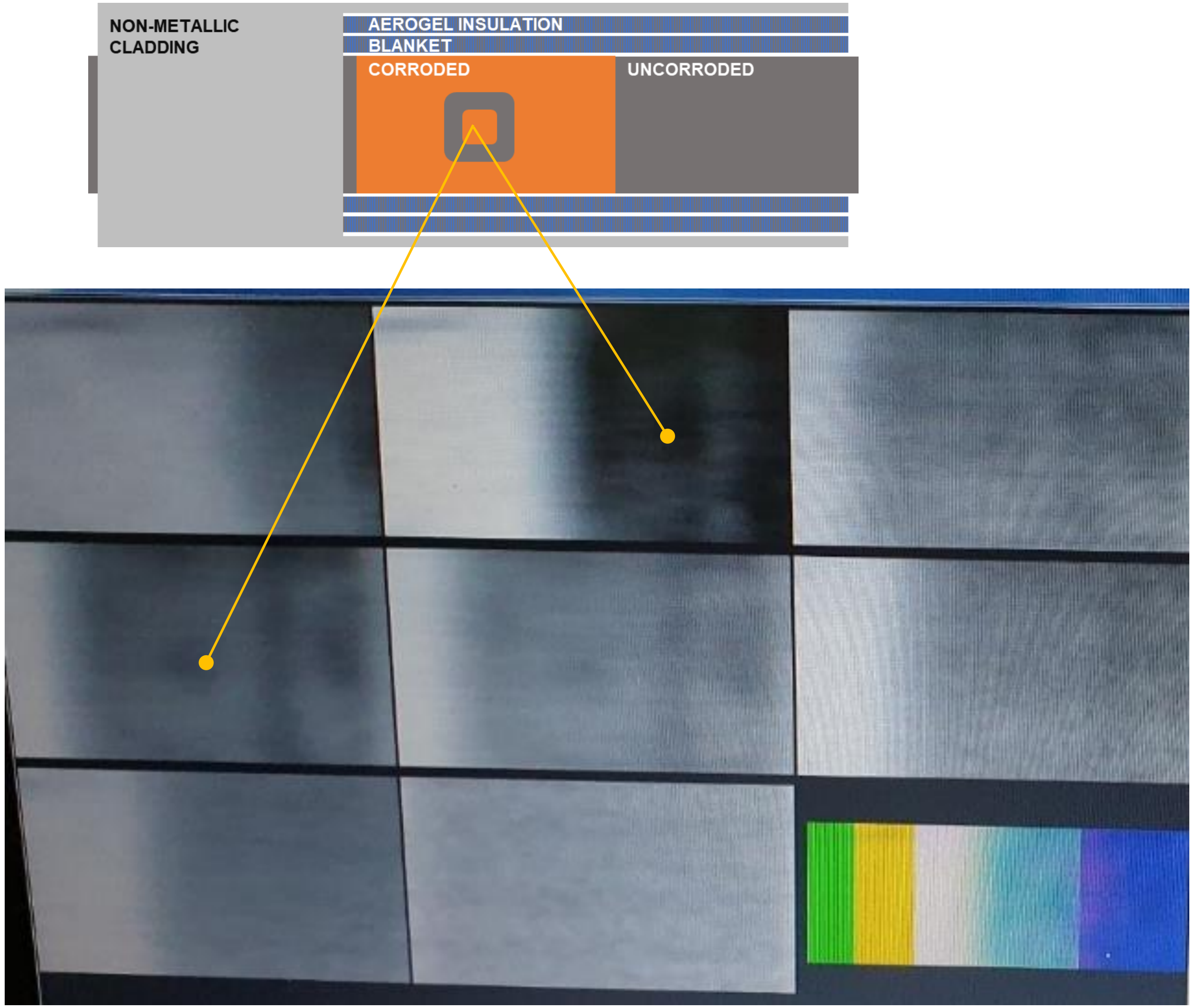
- Coatings
- Paints
- Insulations
- Claddings (Non-metallic)
- Composites (Non-conductive)



Corrosion detection through Multi-layer (thick) insulation coating



Aerogel blankets



Portable detection

- Real time
- Non-contact
- Passive detection

Corrosion **Moisture** **Coatings**

Net Zero Technology Centre
Technology Driving Transition

Further details

Pi – Test & evaluation program 2021

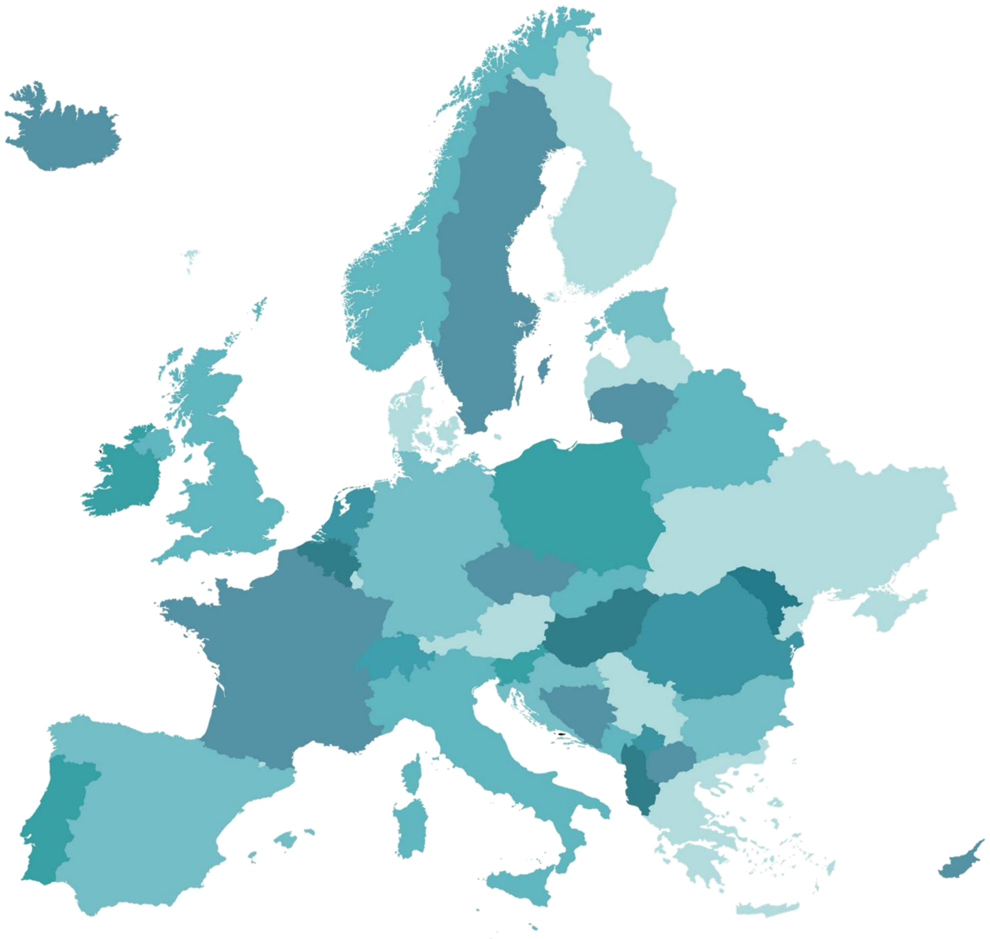
- 5 European trials scheduled

To participate please contact:-

- david.haskett@subterandt.com

Hempel thermally insulating coatings

- Coming soon
- simon.daly@hempel.com



Appendix 5

New 2K heat resistant hybrid siloxane coatings for CUI

(Bart Martens)

New 2K heat resistant hybrid siloxane coatings for CUI

Bart Martens
EFC WP 15

September 2022

Overview

- Introduction
  - NACE SP0198
  - ISO 19277
  - Temperature ranges and chemistry
- Corrosion protection in different stages of an asset's life cycle
- Hybrid systems vs. hybrid products
- Impact on Product selection
- Conclusion

NACE SP0198: Standard Practice Control CUI (A Systems Approach)

Terminology: hybrid

SP0198-2010

Table 2
Typical Protective Coating Systems for Carbon Steels Under Thermal Insulation and Fireproofing

System Number	Temperature Range [A] [B]	Surface Preparation	Surface Profile, µm (mil) [C]	Prime Coat, µm (mil) [D]	Finish Coat, µm (mil) [D]
CS-1	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10[14]	50–75 (2–3)	High-build epoxy, 130 (5)	Epoxy, 130 (5)
CS-2 (shop application only)	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	N/A	Fusion-bonded epoxy (FBE), 300 (12)
CS-3	–45 to 150 °C (–50 to 300 °F)	NACE No. 2/ SSPC- SP 10	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
CS-4	–45 to 205 °C (–50 to 400 °F)	NACE No. 2/ SSPC- SP 10	50–75 (2–3)	Epoxy novolac or silicone hybrid, 100–200 (4–8)	Epoxy novolac or silicone hybrid, 100–200 (4–8)
CS-5	–45 to 595 °C (–50 to 1,100 °F)	NACE No. 1/ SSPC-SP 5[15]	50–100 (2–4)	TSA, 250–375 (10–15) with minimum of 99% aluminum	Optional: S… based or s… service ten… thickness.
CS-6	–45 to 650 °C (–50 to 1,200 °F)	NACE No. 2/ SSPC-SP 10	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)	Inorganic c… multipolym…
CS-7	60 °C (140 °F) maximum	SSPC-SP 2[16] or SSPC-SP 3[17]	N/A	Thin film of petrolatum or petroleum wax primer	Petrolatum…
CS-8 Bulk or shop-primed pipe, coated with inorganic zinc	–45 to 400 °C (–50 to 750 °F)	Low-pressure water cleaning to 3,000 psi (20 MPa) if necessary	N/A	N/A	Epoxy nov… silicone, in… inert multip… the field. C… thickness a…

Epoxy phenolic, 100–150 (4–6)

Epoxy novolac or silicone hybrid, 100–200 (4–8)

Optional: Sealer with either a thinned epoxy-based or silicone coating (depending on maximum service temperature) at approximately 40 (1.5) thickness.

Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)

NACE SP0198 / ISO 19277: chemistries and temperature ranges

Liquid coating*

ISO 19277 defines temperature ranges but does not link them to composition

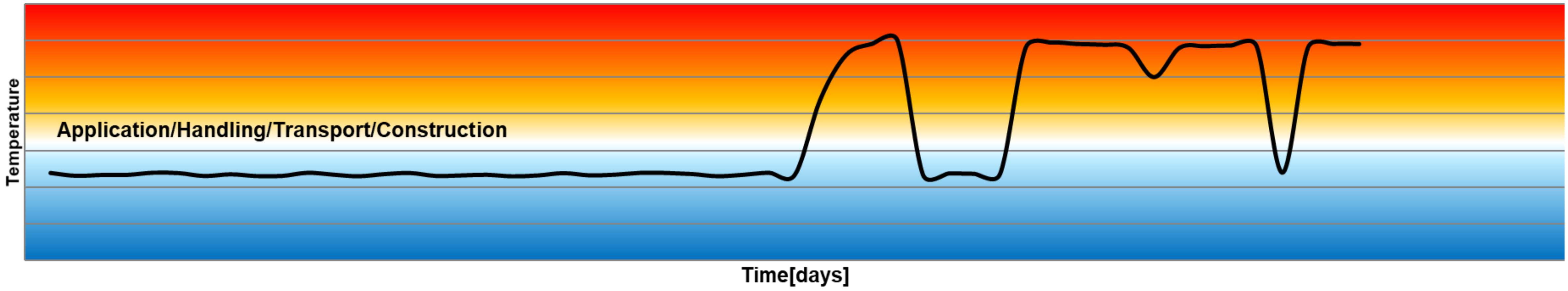
Type	Temp. range	ISO-19277
• Epoxy	-45 to +60°C	(CUI-1)
• Epoxy phenolic	-45 to +150°C	(CUI-2)
• Epoxy Novolac	-45 to +205°C	(CUI-3)
• Silicone hybrid	-45 to +205°C	(CUI-3)
• Inorganic co-polymer / Inert multi-polymeric matrix (IMPM)	-45 to +650°C	(CUI-3)

ISO 19277 and chemistry:

- "This document does not cover sacrificial coatings, such as **inorganic zinc**, as these coatings can be consumed quickly in wet environments. Developing accelerated corrosion testing for what can be continuous wet service with sacrificial coatings is beyond the scope of this document."
- "If testing and acceptance is required, additional testing, as agreed between the interested parties, can be performed."

* Excluding FBE and TSA

Two phases in CUI prevention



Before going into service	In-service

- Ease of application
- Quick hardness development to allow for handling/transportation
- Ambient corrosion resistance (ISO 12944)

- High heat
- Cyclic temperature changes, Thermal shock
- Wet conditions, steam-out
- Out-of-service ambient conditions
- Houston pipe test and CUI chamber (ISO 19277)

Hybrid coating systems

Systems Based on Barrier + Galvanic Protection

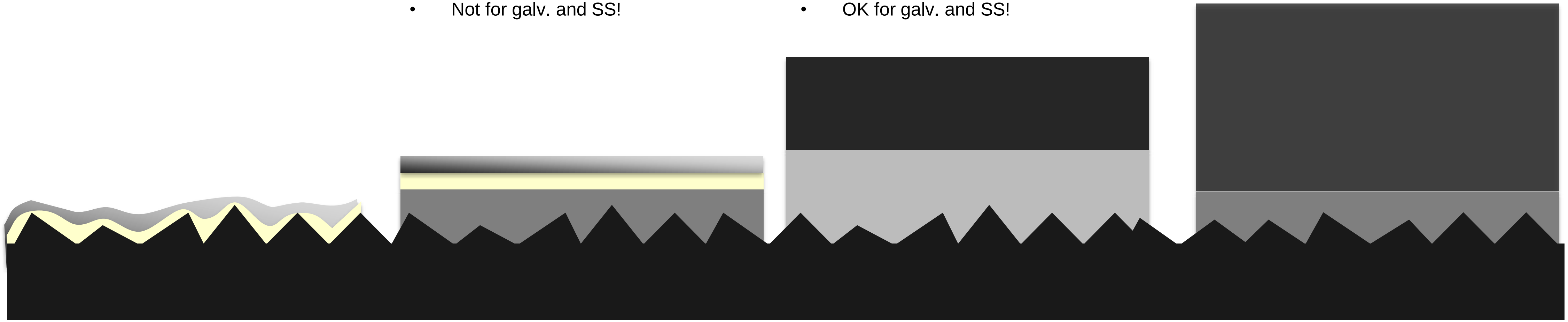
- Blasting profile of 50 µm: peaks covered?
- Barrier against moisture, impact and abrasion?
- Sacrificial galvanic protection? Additional testing, ISO 19277*

Silicone (acrylic)
- 2 coats of 25 µm
- Total DFT = 50 µm
- Barely covers peaks
- Not for CUI
- Can be used to seal galv. and SS

Zinc and Silicone (acrylic)
- 75 µm zinc primer
- 2 coats of 25 µm
- Total DFT = 125 µm
- Galvanic protection (consumable, sealed)
- Covers peaks
- Not for CUI
- Not for galv. and SS!

Phenolic or IMPM
- 2 coats of 125 µm = 250 µm
- Option for one-coat system for Covers peaks + 200 µm
- Extra barrier with DFT (within reason)
- Single coat system possible
- For CUI
- OK for galv. and SS!

Zinc-silicate + Multipolymeric
- 75 µm + 1 or 2 coats > 300 µm
- Covers peaks + 250 µm
- Heavy barrier over galvanic primer
- Additional protection for transport and installation period
- For CUI
- Not for galv. and SS!



Balance of properties

Impact on product selection

- Several manufacturers published about or introduced *hybrid* silicone or *hybrid* multi-polymeric coatings

- Generally 2 component products
  - Chemical reactive agents are kept separate to react only when mixed
  - Workable pot-life vs. the ease of a single component product
  - Faster physical strength build, especially at lower application temperature

Dust-dry
Touch-dry
Dry to overcoat
Dry to handle
Dry to transport
Full-cure / ready for service

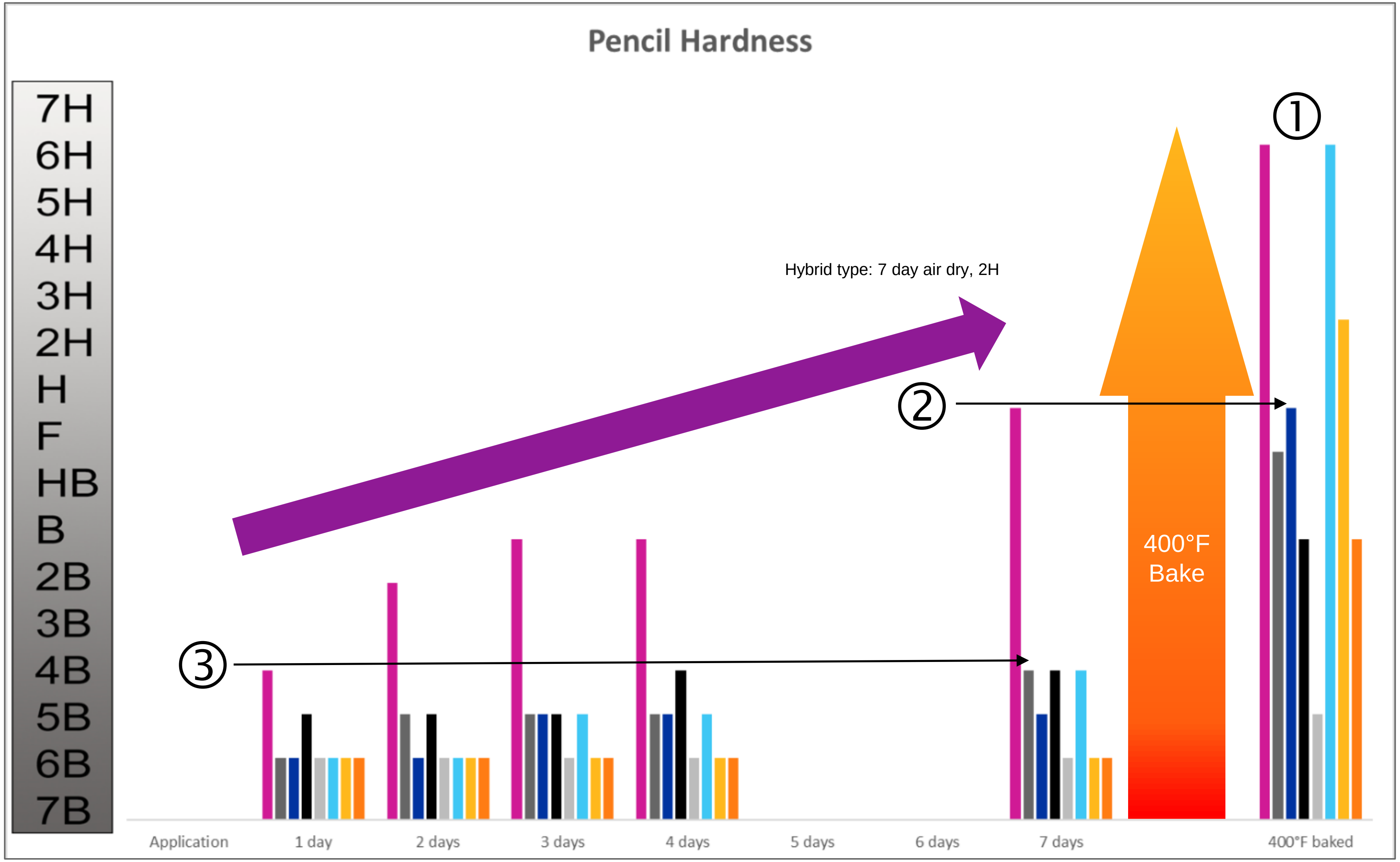
- Temperature resistance window varies
  - Max. 480°C
  - Max. 540°F

  No longer aligned with the NACE temperature windows

  Like most IMPM type products beyond CUI-3 top temperature

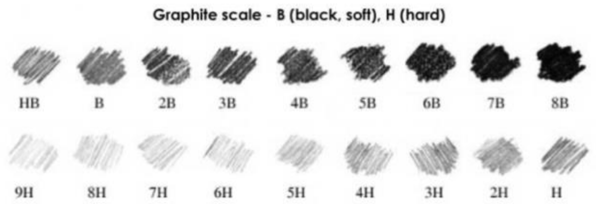
Product comparison

Product Testing – Benchmarking: ambient Cure and Post-cured Hardness



① Level after heat exposure varies
② 2 IMPM component chemistry
③ Most IMPM products

Elcometer 501 Pencil Hardness Tester



Pencil leads - what does HB, 2B etc mean?
pencilsdirect.co.uk

Hybrid coating products

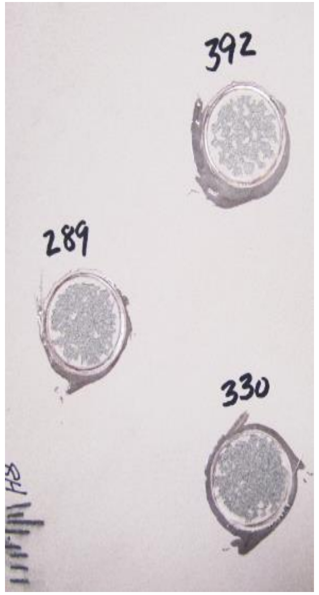
Impact on installation efficiency

- Using the strengths of multiple technologies
  - Combined organic & inorganic chemistries are not new to high temperature coatings:
    - Silicone Acrylics result in harder finish coats after application vs. silicone topcoats,
  - Chemical cure or improved physical drying from a second component
    - Epoxy properties vs. multi-polymeric higher temperature corrosion protection
  - Heat resistance from Si-backbone well beyond CS4 (204°C)
    - Silane, Siloxane, Silicone, multi-polymeric inorganic chemistry

Note: this is not necessarily the same as interpenetrating polymer networks

For a future presentation: can hardness go too far?

Thermal Shock Heat Resistance at 1,200°F (ASTM 2485, modified)



Sample 1: 15 mils

Sample 2

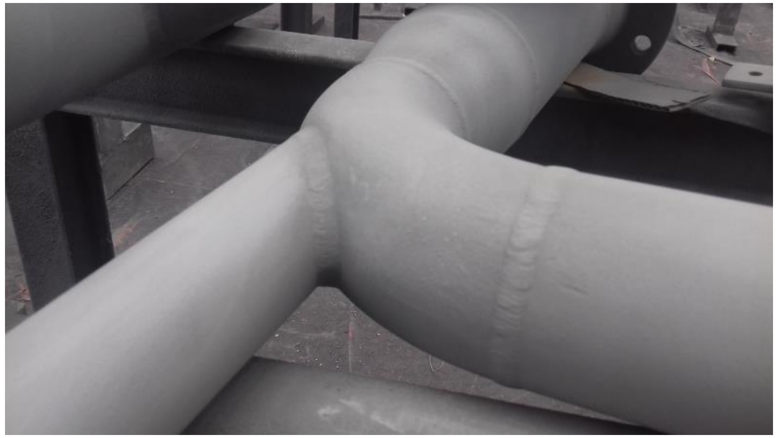
Sample 3

Sample 4

Test Protocol
20 hours (overnight) at temperatures starting at 1,000°F to 1,200°F.
Water quenching after each temperature until 1,200°F.

Conclusion

- With (hybrid) two component chemistry
  - improved physical properties are possible for CUI coatings
  - new options available for when physical strength development is a priority
  - trade off can be peak temperature but may be limited



Appendix 6

Experience with Eddify PEC for CUI and FAC detection

(Alessandro Vanacore)

Donegani Anticorrosione

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23 SEPTEMBER 2021

CORROSION UNDER INSULATION (CUI)

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CORROSION UNDER INSULATION (CUI)

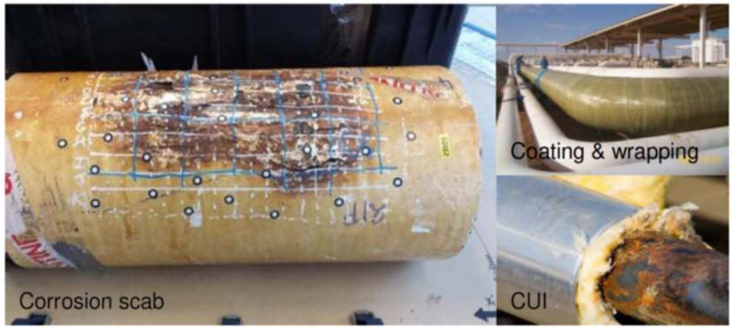
Lyft - Corrosion Assessment Redefined

WHY USE PULSED EDDY CURRENT

Electromagnetic inspection technology is used to detect defects and corrosion in ferromagnetic materials.

Provides a relative wall thickness measurement through liftoff:

- Non-metallic pipe protection (concrete, composite wraps, coatings, and more)
- External corrosion product
- Corrosion under insulation (CUI)
- Marine growth



PEC is a versatile inspection solution!

Eddyfi Technologies

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CORROSION UNDER INSULATION (CUI)

Lyft - Corrosion Assessment Redefined

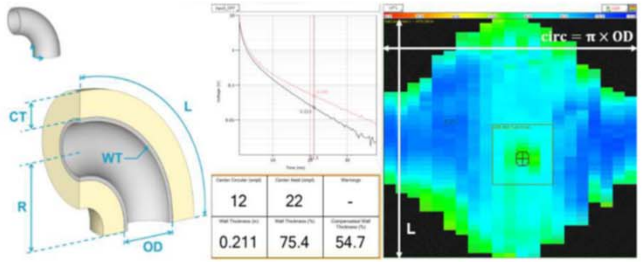
WHY USE PULSED EDDY CURRENT

CUF - Corrosion Under Fireproofing and Concrete

PEC measures remaining wall thickness through concrete, polymer coating, metallic mesh and reinforcing bar

FAC - Flow Accelerated Corrosion

PEC is suitable for measuring corrosion in elbows



Eddyfi Technologies

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CORROSION UNDER INSULATION (CUI)

Lyft - Corrosion Assessment Redefined

WHY USE PULSED EDDY CURRENT

Cast iron inspection

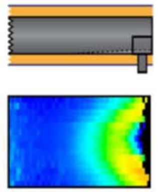
Water and wastewater distribution networks

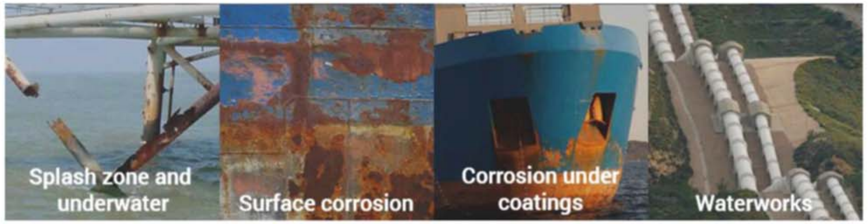
Underwater applications

Underwater and at the splash zone, over marine growth, composite wraps and corrosion product

Limited access inspections

Near supports, valves, metallic structures such as nozzles, flanges, pipe supports





Eddyfi Technologies

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CORROSION UNDER INSULATION (CUI)

Lyft - Corrosion Assessment Redefined

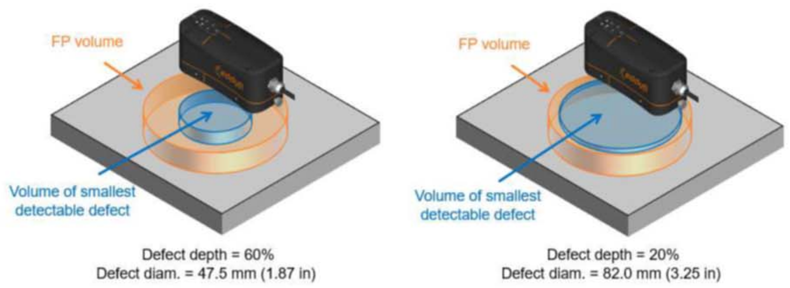
PEC WORKING PRINCIPLES

Smallest detectable defect

Smallest detectable defect volume > 15% of footprint volume

Smaller diameter defects can be detected if depth is increased to maintain a minimum volume ratio of 15% with the footprint

Example: PEC-089-G2 probe + 50.8 mm (2 in) insulation, FP approx. 95 mm (3.75 in)



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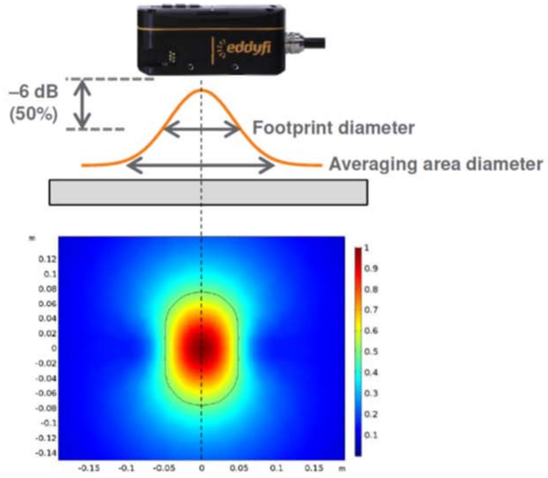
CORROSION UNDER INSULATION (CUI)

PEC WORKING PRINCIPLES

Averaging area

- The footprint area is defined as the area enclosed by the isoline at 50% of the magnetic field B magnitude
- The averaging area is the entire region affecting the signal
- It's diameter corresponds to approximately 1.8 × FP

Defect smaller than averaging area (diameter = 1.8 × FP) is undersized



Typical 2D shape of probe footprint on flat 0.5 in-thick steel plate, 2 in insulation

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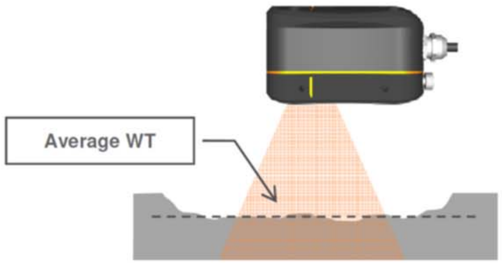
CORROSION UNDER INSULATION (CUI)

PEC WORKING PRINCIPLES

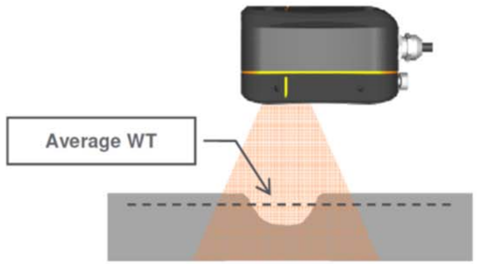
Average wall thickness measurement impact

- Defect larger than the averaging area = sizing accuracy +/- 10%
- Defect smaller than the averaging area = undersizing

The thicker walls around the indication influence the averaging calculation



Good sizing accuracy



Defect undersizing

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CORROSION UNDER INSULATION (CUI)

PEC WORKING PRINCIPLES

Limitations of the technology:

- Screening tool, measurement is relative to the calibration area
- Unable to discriminate near-side and far-side defects
- Impossible to detect small pitting
- Undersizing of flaws smaller than the averaging area of the probe

  But, the **Compensated Wall Thickness (CWT)** sizing tool is used for better measurement accuracy.

- Edge effect near metallic structures

  But, the **Compensated Wall Thickness (CWT)** sizing tool is used to compensate for the electromagnetic contribution of masses such as flange, resulting in better flaw sizing.

- Impossible to detect through hole defects

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CORROSION UNDER INSULATION (CUI)

It is possible test: pipes, vessels, coloumns or skirt with hot/cold insulation, fireproofing, rubber plastic and so on…

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CORROSION UNDER INSULATION (CUI)

Old windows opened for traditional UT tk measurements. In some case if the new plate it is not replaced correctly could be a point were water can penetrate a start CUI. In some other case, window after window the insulation can collapse and results in addictional problems of safety, heat dissipation.

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CORROSION UNDER INSULATION (CUI)

Probes can be handled easily by one operator directly or with the support of the dedicate extendable rod

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CORROSION UNDER INSULATION (CUI)

Supports, valves, vents, very short pipes are limitations for the test

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CORROSION UNDER INSULATION (CUI)

Poor quality of the insulation or jacket could result in:
high noise or impossibility to test the item

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CORROSION UNDER INSULATION (CUI)

In addiction to damaged jacket we find encumbrance from structures or other pipes or sometimes the insultaion is partially relaced after TA.



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CORROSION UNDER INSULATION (CUI)

Fireproofing damages like cracks or vacancies can be the INLET point for umidity as rainin water, fire water or steam condensate and give the start for CUI on skirt.
In some case in the area of damaged fireproofing we detect relevant corrosion.

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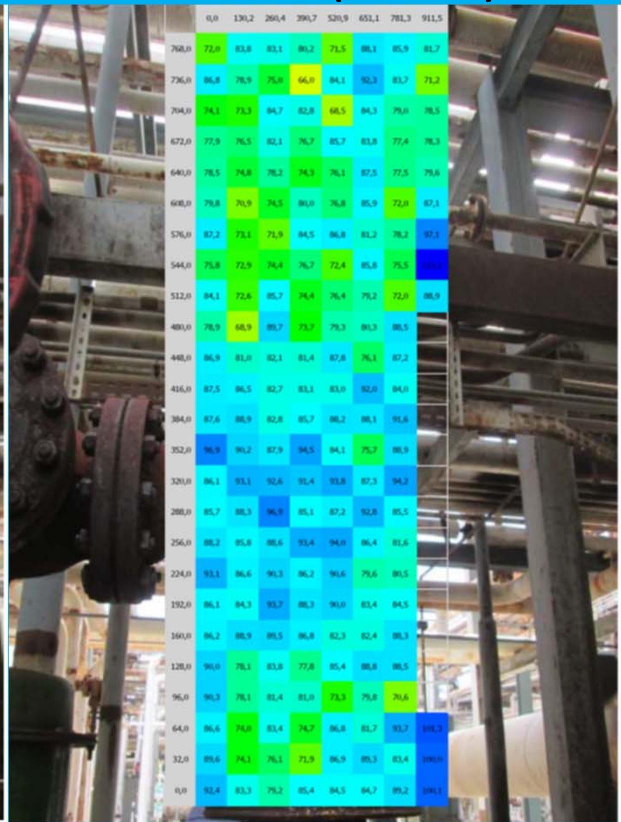
CORROSION UNDER INSULATION (CUI)

	0,0	260,4	520,9	781,3
711,1	83,7	86,1	86,6	91,8
622,2	78,8	80,0	83,4	79,8
533,3	74,7	82,0	84,7	89,2
444,4	79,9	79,8	85,9	101,1
355,6	86,1	86,9	88,3	
266,7	86,8	88,8	87,8	
177,8	87,5	86,2	87,8	
88,9	84,0	83,0	85,7	101,8
0,0	84,0	81,2	85,4	100,0



	0,0	130,2	260,4	390,7	520,9	651,1	781,3	911,5
768,0	72,0	83,8	83,1	80,2	71,5	88,1	85,9	81,7
736,0	86,8	78,9	75,0	66,0	84,1	92,3	83,7	71,2
704,0	74,1	73,3	84,7	82,8	68,5	84,3	79,0	78,5
672,0	77,9	76,5	82,1	76,7	85,7	83,8	77,4	78,3
640,0	78,5	74,8	78,2	74,3	76,1	87,5	77,5	79,6
608,0	79,8	70,9	74,5	80,0	76,8	85,9	72,0	87,1
576,0	87,2	73,1	71,9	84,5	86,8	81,2	78,2	97,1
544,0	75,8	72,9	74,4	76,7	72,4	85,8	75,5	[illegible]
512,0	84,1	72,6	85,7	74,4	76,4	79,2	72,0	88,9
480,0	78,9	68,9	89,7	73,7	79,3	80,3	88,5	
448,0	86,9	81,0	82,1	81,4	87,8	76,1	87,2	
416,0	87,5	86,5	82,7	83,1	83,0	92,0	84,0	
384,0	87,6	88,9	82,8	85,7	88,2	88,1	91,6	
352,0	96,9	90,2	87,9	94,5	84,1	75,7	88,9	
320,0	86,1	93,1	92,6	91,4	93,8	87,3	94,2	
288,0	85,7	88,3	96,9	85,1	87,2	92,8	85,5	
256,0	88,2	85,8	88,6	93,4	94,0	86,4	81,6	
224,0	93,1	86,6	90,3	86,2	90,6	79,6	80,5	
192,0	86,1	84,3	93,7	88,3	90,0	83,4	84,5	
160,0	86,2	88,9	89,5	86,8	82,3	82,4	88,3	
128,0	90,0	78,1	83,8	77,8	85,4	88,8	88,5	
96,0	90,3	78,1	81,4	81,0	73,3	79,8	70,6	
64,0	86,6	74,0	83,4	74,7	86,8	81,7	93,7	101,3
32,0	89,6	74,1	76,1	71,9	86,9	89,3	83,4	100,0
0,0	92,4	83,3	79,2	85,4	84,5	84,7	89,2	100,1

FIRST TEST EVER CONDUCED BY DONEGANI.

WE ALREADY KNOW THE PROBLEM OF THE PIPE – GENERAL AND SEVERE LOCALISED CORROSION.
FIRST TEST – JUST TO HAVE AN IDEA....
WE DETECT CORROSION AND GO DEEPER INTO THE LYFT SCANNING THE PIPE.
THE RESULTS IS QUITE SIMILAR TO PREVIOUS UT TKMEASUREMENTS

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CORROSION UNDER INSULATION (CUI)

Wall thickness values

Color palette legend

8,0	8,7	9,5	10,2	10,9	11,7	12,4	13,2	13,9	14,6	15,4	16,1	16,8	17,6	18,3	19,1	19,8	20,5	21,3

	750,0	784,1	818,2	852,3	886,4	920,5	954,5	988,6	1022,7	1056,8	1090,9	1125,0	1159,1	1193,2	1227,3	1261,4	1295,5	1329,5	1363,6	1397,7	1431,8	1465,9
1187,5	21,2	21,2	21,4	21,3	21,3	21,1	21,5	21,3	21,9	21,8	21,2	20,8	22,0	20,7	21,0	21,4	21,5	21,7	21,2	21,5	20,7	21,6
1125,0	21,3	21,3	21,1	21,1	21,3	21,2	21,2	22,7	21,6	21,7	21,7	21,6	22,0	22,8	22,1	21,8	21,4	21,6	20,9	21,2	21,3	21,4
1062,5	21,3	21,3	21,2	21,2	21,3	21,1	21,1	21,2	20,4	22,1	21,5	21,9	21,6	21,5	21,7	20,3	21,6	21,1	21,3	21,5	20,9	20,9
1000,0	21,1	21,1	21,1	21,3	21,1	21,1	21,1	21,1	21,3	21,9	21,3	21,1	21,2	21,2	21,2	21,6	21,1	20,5	20,7	20,0	20,1	20,4
937,5	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,1	21,0	21,0	25,8	20,3	20,2	20,3
875,0	20,4	20,4	20,1	20,6	20,5	20,5	20,1	19,9	20,0	19,5	19,8	20,0	20,1	20,0	20,1	20,0	19,9	20,5	20,0	20,2	20,0	20,2
812,5	20,2	20,2	20,2	20,6	20,9	21,0	21,2	21,3	21,3	21,3	21,3	20,9	21,2	21,0	21,2	21,2	21,2	22,1	20,3	21,1	21,3	21,1
750,0	19,9	20,8	21,6	21,8	21,9	22,2	21,9	21,9	21,9	21,9	21,5	21,1	19,9	20,5	20,8	20,1	21,0	20,9	21,6	21,1	21,5	21,0

Tank shell tested – results,
90% of the values are higher than nominal thikness,
calibration to be redone at end of the scanning by the software.

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CORROSION UNDER INSULATION (CUI)

Wall thickness values

Color palette legend

10,0 | 10,4 | 10,8 | 11,2 | 11,6 | 12,0 | 12,4 | 12,8 | 13,2 | 13,6 | 14,0 | 14,4 | 14,8 | 15,2 | 15,6

	250,0	321,4	392,9	464,3	535,7	607,1	678,6	750,0	821,4	892,9	964,3	1035,7	1107,1	1178,6
14357,1	16,0	15,8	14,9	15,1	15,7	15,1	15,5	14,3	14,5	14,4	14,5	14,1	14,7	14,9
14214,3	15,9	14,6	14,5	14,3	12,6	13,9	13,9	14,1	14,2	14,6	15,0	15,0	15,1	15,1
14071,4	15,2	14,8	13,6	14,5	14,7	14,3	14,3	13,6	14,7	13,9	14,9	14,6	13,7	15,2
13928,6	15,7	15,4	14,8	14,0	13,8	14,7	13,5	14,4	14,8	14,9	14,9	14,8	15,1	15,1
13785,7	15,3	15,0	15,2	16,0	15,9	15,9	15,6	14,6	14,8	14,3	14,6	15,5	15,1	15,0
13642,9	14,9	16,1	16,4	15,2	14,3	15,4	14,7	15,1	15,1	15,5	15,5	15,6	15,1	15,6
13500,0	16,2	15,7	16,1	15,7	15,6	14,7	15,2	14,2	15,3	14,7	15,8	15,6	15,9	16,0

Wall thickness values

Color palette legend

9,0 | 9,5 | 9,9 | 10,4 | 10,8 | 11,3 | 11,7 | 12,2 | 12,6 | 13,1 | 13,5 | 14,0 | 14,4 | 14,9 | 15,3

	250,0	321,4	392,9	464,3	535,7	607,1	678,6	750,0	821,4	892,9	964,3	1035,7	1107,1	1178,6
5357,1	13,2	11,7	11,5	11,2	11,2	11,2	10,9	10,6	10,5	10,3	10,3	10,7	11,1	11,1
5214,3	12,9	12,6	12,7	13,1	11,9	11,2	11,2	10,5	10,6	10,6	10,9	10,9	10,8	10,9
5071,4	11,7	11,8	11,6	11,0	11,1	11,1	11,1	10,9	11,2	11,1	11,2	11,4	11,6	11,6
4928,6	12,0	11,6	12,3	12,4	11,4	11,8	11,3	11,3	11,2	11,1	11,1	11,7	10,9	10,9
4785,7	11,8	12,2	11,8	11,9	11,3	11,4	11,3	10,8	11,0	11,3	11,5	11,0	10,9	12,2
4642,9	11,8	11,5	12,1	11,7	12,3	11,2	11,0	11,2	11,1	10,9	10,9	11,3	11,8	11,5
4500,0	12,5	12,0	11,6	11,4	11,2	11,1	10,5	10,6	11,1	10,8	10,8	10,5	11,1	11,3

EXEMPLES OF SCANNING WITH SOME THINY POINT (L) AND THINNED AREA (R)

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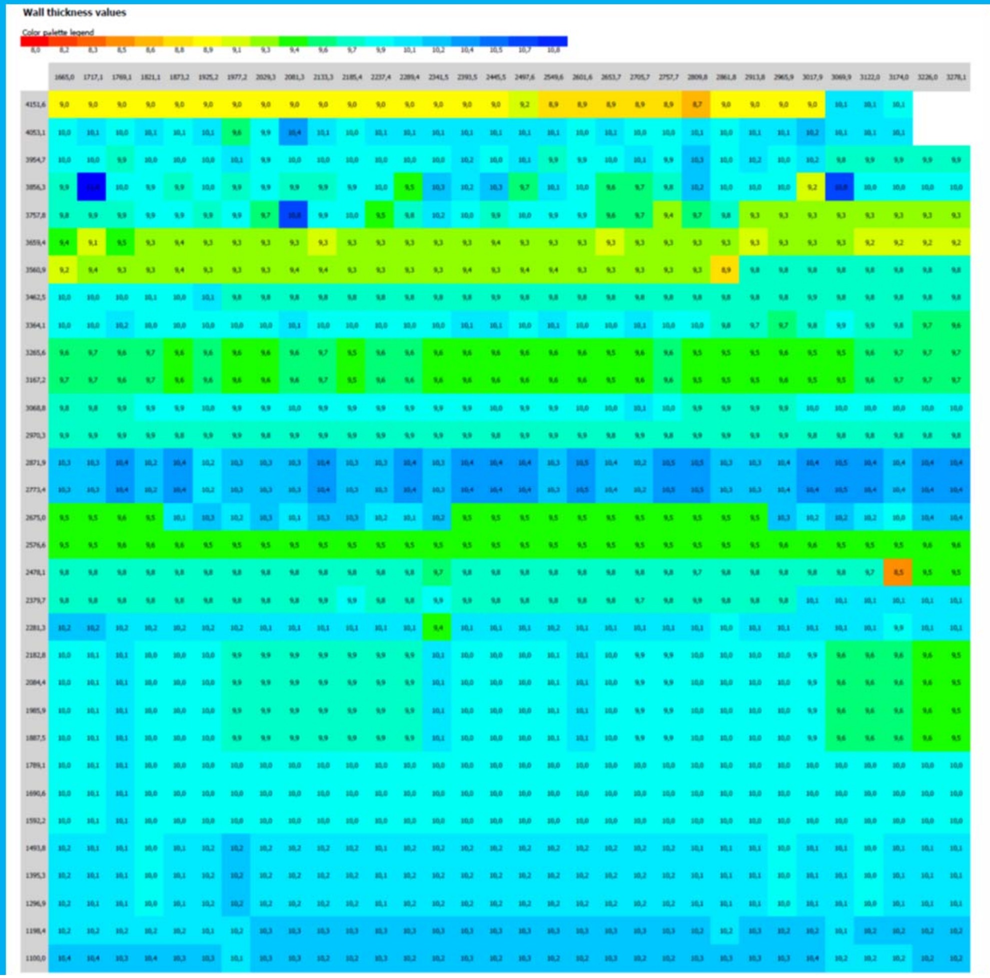
CORROSION UNDER INSULATION (CUI)

Wall thickness values

Color palette legend

8,0	8,7	9,5	10,2	10,9	11,7	12,4	13,2	13,9	14,6	15,4	16,1	16,8	17,6	18,3	19,1	19,8	20,5	21,3

	5500,0	5533,3	5566,7	5600,0	5633,3	5666,7	5700,0	5733,3	5766,7	5800,0	5833,3	5866,7	5900,0	5933,3	5966,7
5937,5	21,8	21,8	21,6	21,7	21,7	21,8	19,0	18,1	18,0	18,1	18,1	18,1	18,1	18,1	18,2
5875,0	21,3	21,3	21,4	21,4	21,6	21,5	21,5	18,7	19,6	18,2	18,1	18,1	18,1	18,1	18,1
5812,5	21,4	22,1	21,6	21,4	21,6	21,4	20,5	21,9	20,0	19,9	20,0	19,9	19,9	19,8	20,0
5750,0	21,9	21,8	21,2	21,6	21,5	21,5	21,5	21,4	19,3	19,6	19,7	19,7	19,7	19,6	19,9
5687,5	21,3	21,3	22,7	22,5	23,4	22,2	20,6	18,1	19,1	20,0	20,4	20,1	19,5	19,5	19,5
5625,0	21,2	21,2	21,3	21,7	21,8	22,1	22,3	21,6	20,8	18,7	18,8	19,2	20,2	19,5	19,4
5562,5	21,3	21,1	21,2	21,2	21,1	21,3	21,7	22,3	20,4	18,1	19,6	18,2	18,4	19,4	19,4
5500,0	21,2	21,2	21,2	21,1	21,2	21,2	22,4	21,8	21,0	19,1	18,5	19,3	19,3	19,4	19,4



SMALL AREA (L) VS BIG AREA (R)

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CORROSION UNDER INSULATION (CUI)

ALMOST REGULAR VALUES
THE AVERAGE OF TK IS A LIGHTLY LOWER THAN NOMINAL TK WITH SOME TINY SPIKE POINT

Wall thickness values

Color palette legend

3,8 4,2 4,5 4,9 5,2 5,6 5,9 6,3 6,6 7,0 7,3 7,7 8,0 8,4 8,7 9,1 9,4 9,8 10,1

	0,0	76,7	153,5	230,2	306,9	383,7	460,4	537,2	613,9	690,6	767,4	844,1	920,8
5382,4	9,3	9,4	9,3	9,4	9,4	9,5	9,5	9,7	9,7	9,8	9,7	9,7	9,6
5264,7	10,8	9,4	9,4	9,5	9,5	9,4	9,4	9,4	9,5	9,5	9,6	9,7	9,7
5147,1	9,5	9,4	9,5	9,5	9,6	9,5	9,6	9,8	9,8	9,7	9,7	9,6	9,7
5029,4	9,3	9,3	9,4	9,4	9,4	9,5	9,5	9,4	9,5	9,7	9,6	9,7	9,7
4911,8	9,2	9,5	9,4	9,3	9,4	9,5	9,4	9,5	9,5	9,6	9,6	9,7	9,6
4794,1	9,3	9,3	9,3	9,3	9,3	9,4	9,4	9,6	9,8	9,7	9,7	9,6	9,6
4676,5	9,2	9,2	9,3	9,3	9,2	9,2	9,2	9,4	9,5	9,7	9,7	9,7	9,6
4558,8	9,2	9,2	9,2	9,2	9,2	9,3	9,3	9,3	9,4	9,4	9,6	9,6	9,8
4441,2	9,1	9,1	9,1	9,1	9,1	9,2	9,2	9,2	9,2	9,4	9,5	9,6	9,7
4323,5	9,1	9,2	9,3	9,3	9,3	9,3	9,3	9,4	9,5	9,5	9,6	9,7	9,6
4205,9	9,3	9,3	9,3	9,3	9,1	9,3	9,3	9,2	9,1	9,0	9,1	9,0	8,9
4088,2	9,4	9,6	9,4	9,5	9,6	9,4	9,5	9,3	9,4	9,4	9,4	9,4	9,2
3970,6	9,4	10,2	9,4	9,4	9,3	9,5	9,5	9,4	9,7	9,6	9,5	9,5	9,4
3852,9	10,8	9,7	9,8	9,7	9,7	9,5	9,6	9,6	9,7	9,8	10,0	10,0	10,1
3735,3	9,4	9,1	9,4	9,1	9,5	10,1	9,2	8,9	9,6	9,8	9,4	9,8	9,7
3617,6	9,4	9,3	9,3	9,3	9,3	9,4	9,4	9,4	9,5	9,5	9,5	9,6	9,9
3500,0	8,3	8,9	8,9	8,8	8,8	8,9	9,0	9,0	8,9	8,8	8,8	9,0	9,0

	997,6	1074,3	1151,0	1227,8	1304,5	1381,3	1458,0	1534,7	1611,5	1688,2	1764,9	1841,7	1918,4	1995,1
5382,4	9,4	9,5	9,4	9,4	9,4	9,3	9,4	9,4	9,4	9,4	9,4	9,4	9,4	9,3
5264,7	9,7	9,8	9,6	9,7	9,8	9,6	9,5	9,4	9,4	9,4	9,4	9,3	9,4	9,4
5147,1	9,8	9,5	9,5	9,4	9,5	9,4	9,4	9,4	9,4	9,4	9,3	9,4	9,4	9,3
5029,4	9,8	9,6	9,6	9,6	9,7	9,9	9,5	9,5	9,4	9,4	9,3	9,4	9,4	9,3
4911,8	9,6	9,4	9,6	9,4	9,4	9,4	9,3	9,3	9,3	9,3	9,3	9,2	9,3	9,2
4794,1	9,6	9,6	9,5	9,6	9,5	9,4	9,4	9,3	9,3	9,3	9,3	9,3	9,2	9,3
4676,5	9,5	9,6	9,4	9,3	9,2	9,2	9,2	9,2	9,2	9,2	9,2	9,2	9,2	9,1
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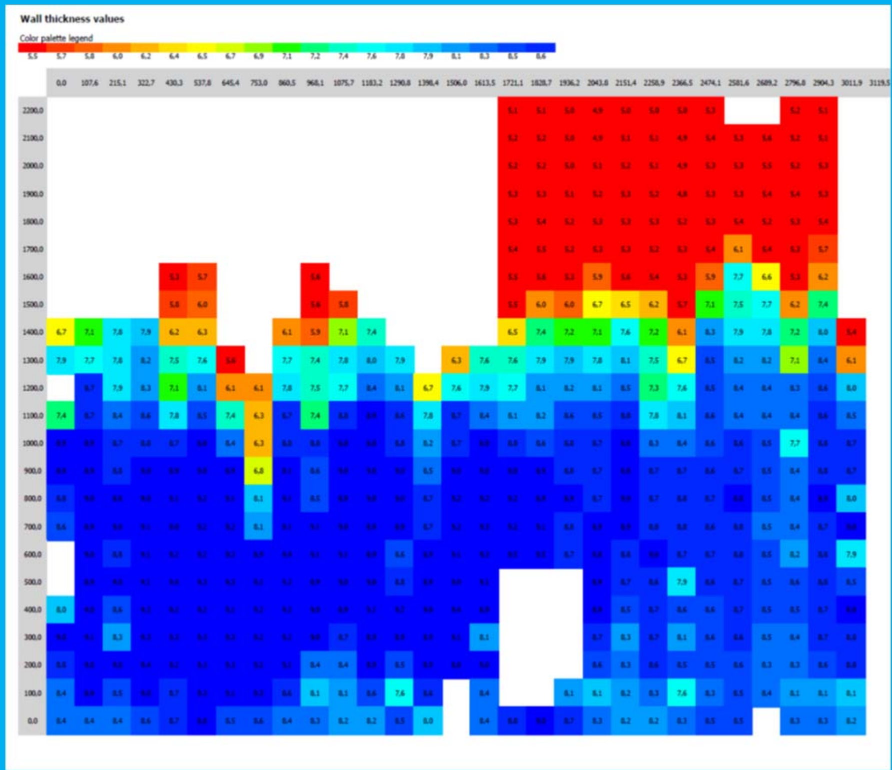
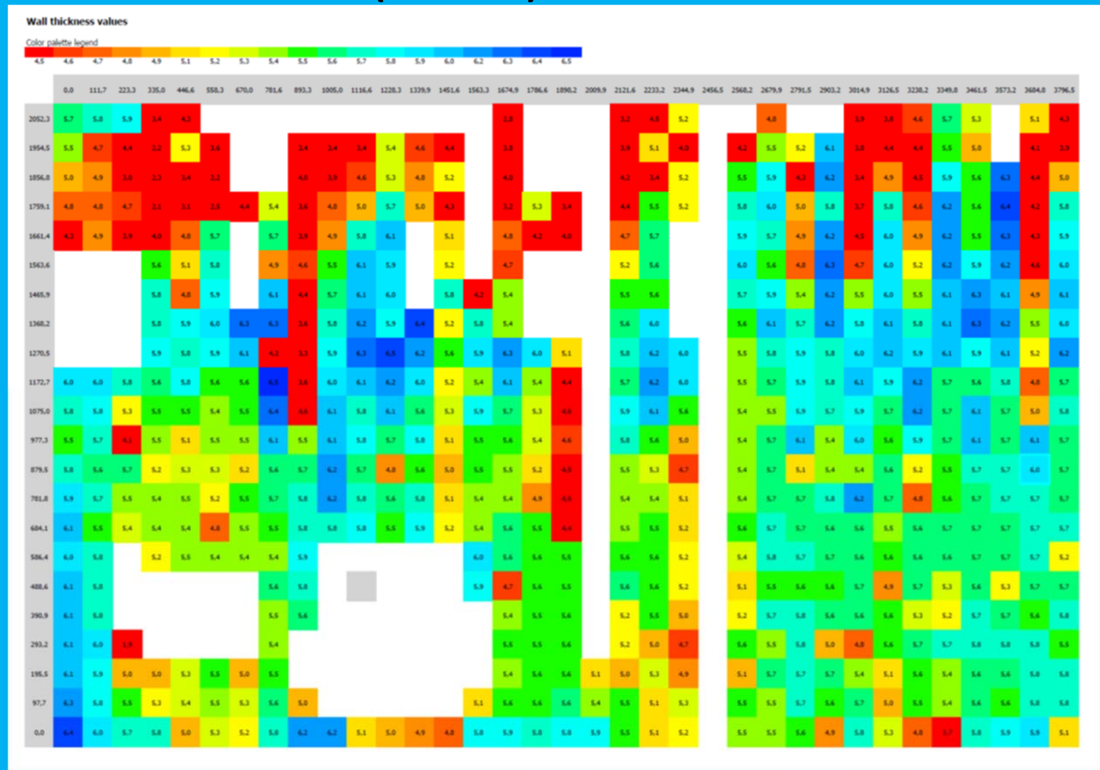
4088,2	9,1	8,9	8,6	9,5	9,6	9,5	9,5	9,6	9,5	9,5	9,5	9,6	9,5	9,6
3970,6	9,5	9,4	9,6	9,5	9,4	9,4	9,4	9,4	9,4	9,4	9,4	9,5	9,5	9,5
3852,9	10,0	10,2	10,1	9,9	9,9	9,8	9,6	9,7	9,6	9,6	9,7	9,6	9,7	9,7
3735,3	9,7	9,5	9,4	9,4	9,4	9,3	9,3	9,3	9,4	9,4	9,4	9,4	9,4	9,7
3617,6	9,8	9,8	9,7	9,7	9,6	9,4	9,3	9,3	9,2	9,3	9,3	9,2	9,3	9,2
3500,0	9,4	9,6	9,8	9,6	9,4	9,3	9,2	9,2	9,2	9,2	9,2	9,3	9,2	9,3

Donegani
Anticorrosione

EFC WP15 - 23 SEPTEMBER 2021
CORROSION UNDER INSULATION (CUI)

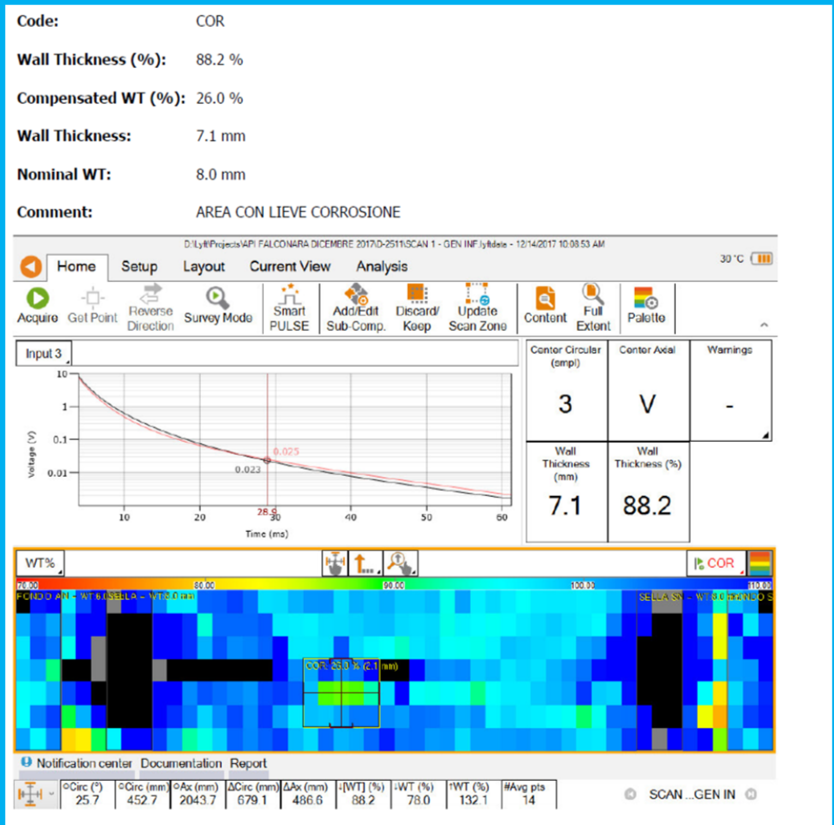




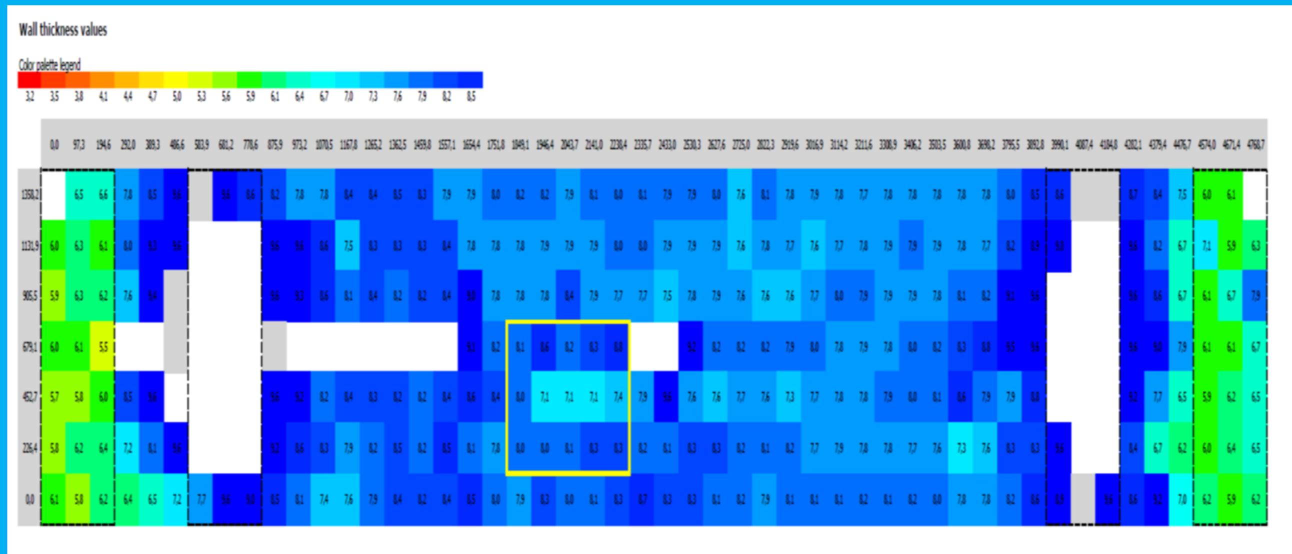
FIREPROOFED SKIRT INSPECTION – THE TOP SIDE (PTROTECTIVE LAYER DAMAGED) SHOW SEVERE CORROSION

Donegani Anticorrosione

EFC WP15 - 23 SEPTEMBER 2021
CORROSION UNDER INSULATION (CUI)



THE SOFTWARE GIVE THE POSSIBILITY TO HIGHLIGHT CORRODED AREAS (OR OTHER TYPE OF INDICATION) AND RECALCULATE WITH HIGHER PRECSION THE VALUES OF SPECIFIC CORRODED AREA.



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EFC WP15 - 23 SEPTEMBER 2021
CORROSION UNDER INSULATION (CUI)

Screen Capture Appendix

Filename: SCAN 2 TUBO

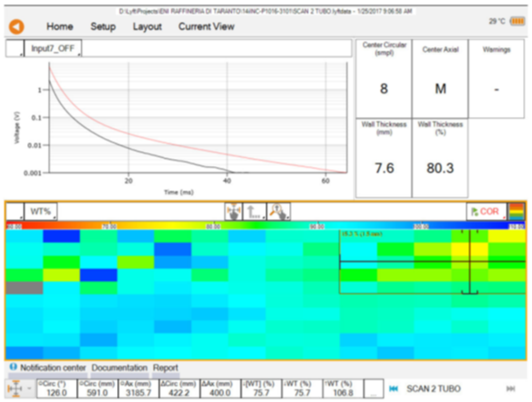
Code: COR

Size: 80.3 %

Wall Thickness 7.6 mm

Nominal WT: 9.5 mm

Comment:



Screen Capture Appendix

Filename: SCAN 2 LINEA

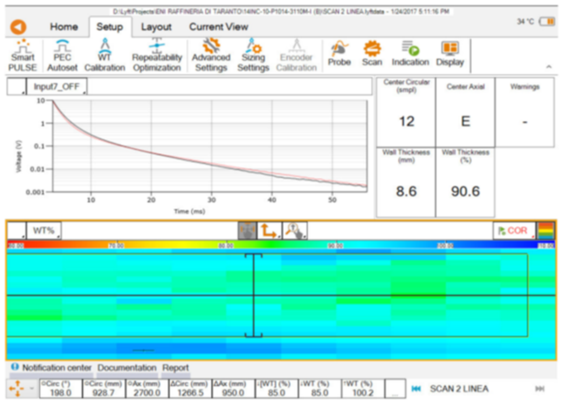
Code: COR

Size: 90.6 %

Wall Thickness 8.6 mm

Nominal WT: 9.5 mm

Comment:



Filename: SCAN1 LINEA

Code: COR

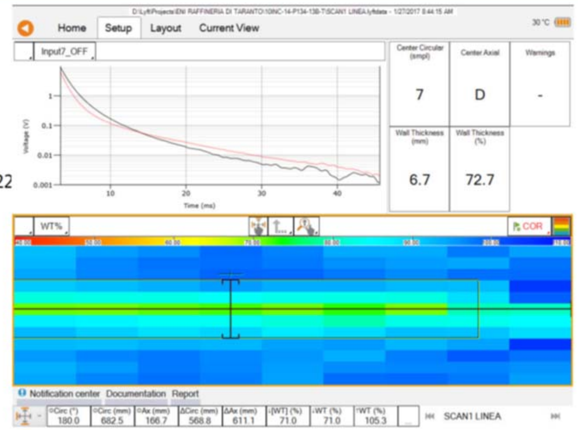
Size: 72.7 %

Wall Thickness 6.7 mm

Bollettino PEC/022

Nominal WT: 9.3 mm

Comment:



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EFC WP15 - 23 SEPTEMBER 2021
CORROSION UNDER INSULATION (CUI)

MANY THANKS TO ALL THE ATTENDERS

Alessandro Vanacore
Capo Dipartimento Controlli non Distruttivi
3° Livello VT-PT-MT-ET-UT-PAUT-TOFD-AE-LT UNI EN ISO 9712
2° Livello RE-ME-TT UNI EN ISO 9712
Ispettore PED – ambito di Approvazioni 3.1.3 – numero identificativo 150 in collaborazione con ICEPI

Donegani Anticorrosione s.r.l.
Via G. Fauser, 36/A
28100 – Novara (NO)
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Mobile 0039/342 3233032

Donegani Anticorrosione

Appendix 7

Online Risk Monitoring of CUI for Cold Insulation Pressure Vessels and Pipelines

(Prafull Sharma)

EFC Work Party 15
Corrosion In Refinery and Petrochemicals
Annual Meeting
23rd September 2021

Online Risk Monitoring of CUI for Cold Insulation Pressure Vessels and Pipelines

Dr Prafull Sharma, UK

p.sharma@corrosionradar.com

The Dilemma of CUI

How can we be smarter?

Is CUI one of the damage mechanisms in your plant (including SCC)

How are you managing CUI currently (Coatings, Insulations, Inspections, RBI etc)

How can the CUI management be improved?

When and where are risks to – Insulation, Coatings, CUI?

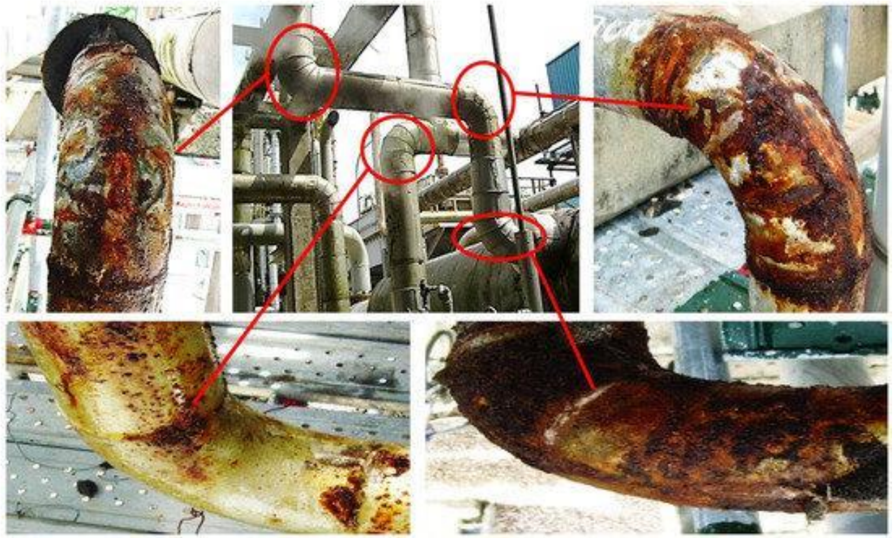
Corrosion Under Insulation (CUI)

CUI IS AMONG THE TOP ASSET INTEGRITY ISSUES

CUI is #1 asset integrity issue in O&G and Petrochemicals

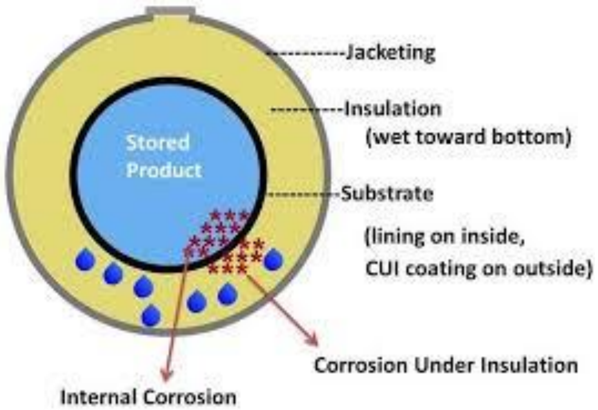
60% of all pipeline failures are due to CUI

10% of the overall offshore platforms maintenance cost

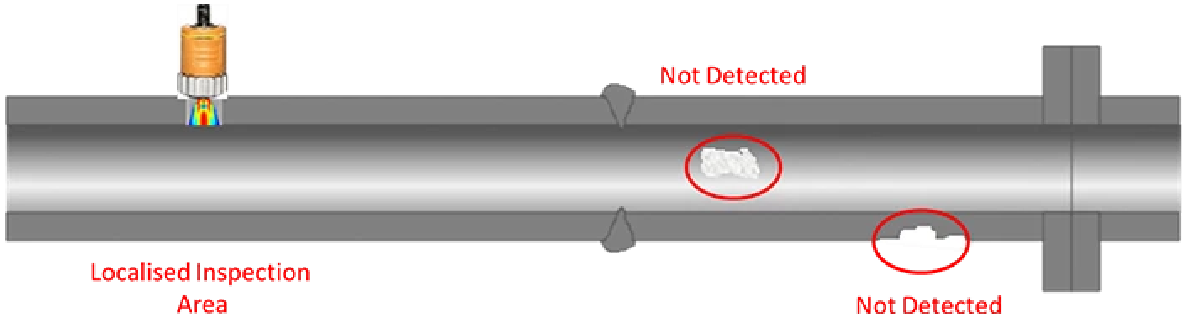


How CUI happens

Water ingress into insulation



Unpredictable location



Suitable temperature

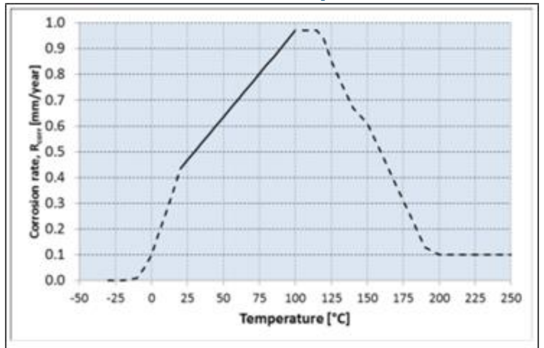


Figure A-3: Corrosion rate (Rcorr) vs. temperature

Predictive Corrosion Management

ENABLED BY IIOT AND PREDICTIVE ANALYTICS

CURRENT PRACTICE
Reactive

HUMAN JUDGEMENT + GUESSED RISK ↔ PERIODIC MANUAL INSPECTION

REACTIVE MAINTENANCE

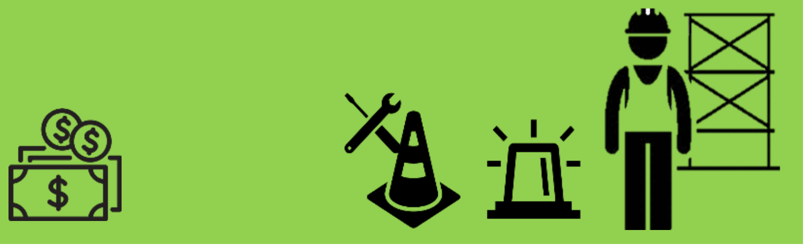
- Labour Intensive
- Unscheduled Shutdowns
- Safety Risk
- High cost

EMERGING PRACTICE
Predictive

Sensors – Connectivity → CONTINUOUS MONITORING ↔ AUTOMATED RISK PROFILING ← Analytics / ML – Knowledgebase

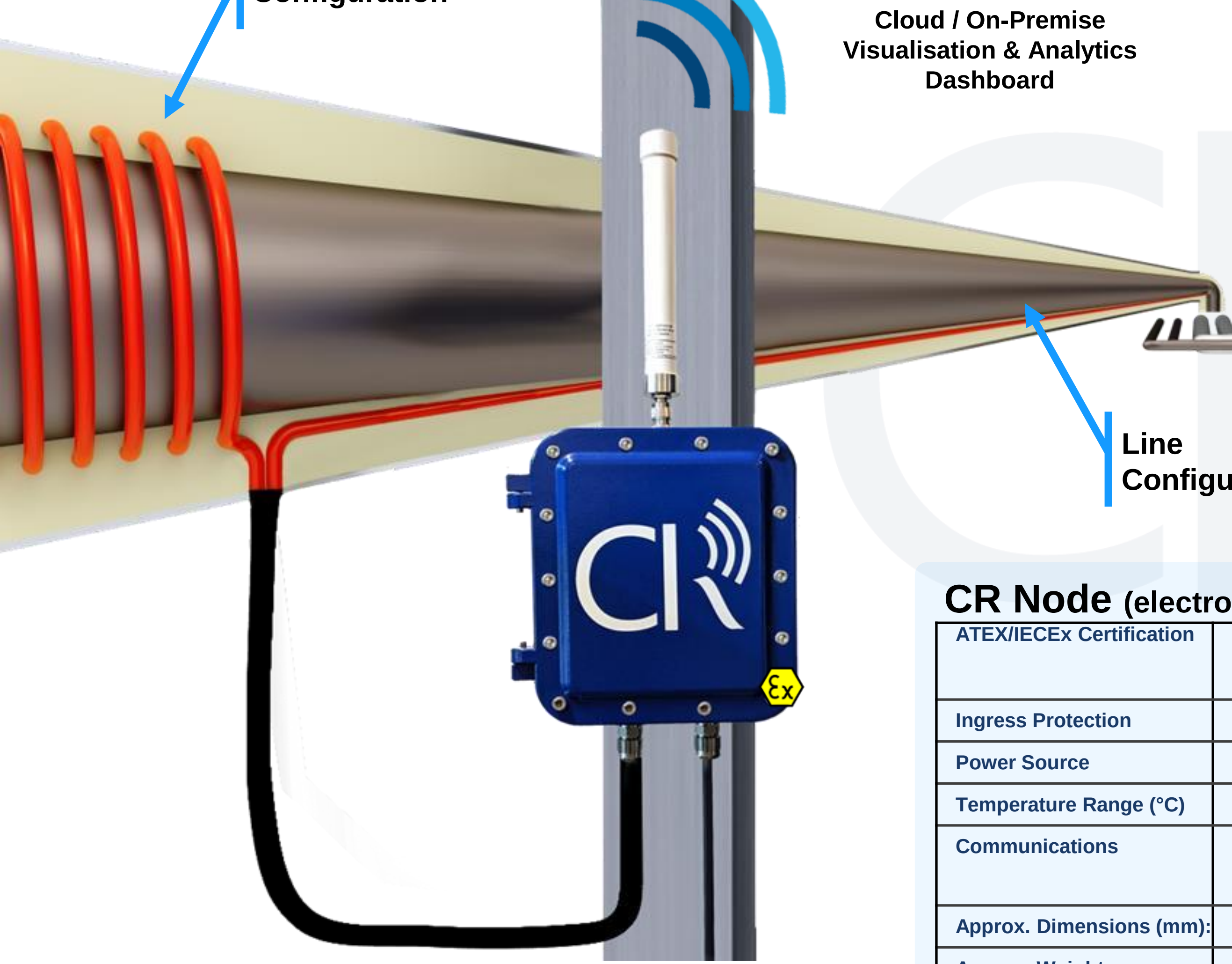
PREDICTIVE MAINTENANCE

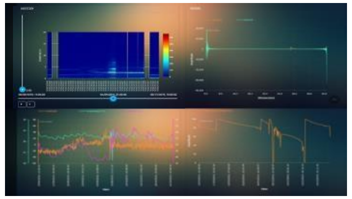
- Minimal labour effort
- Scheduled Maintenance
- Improved safety
- Reduced cost



CUI Monitoring System

Corrosion and Moisture Sensors for Predictive CUI Management

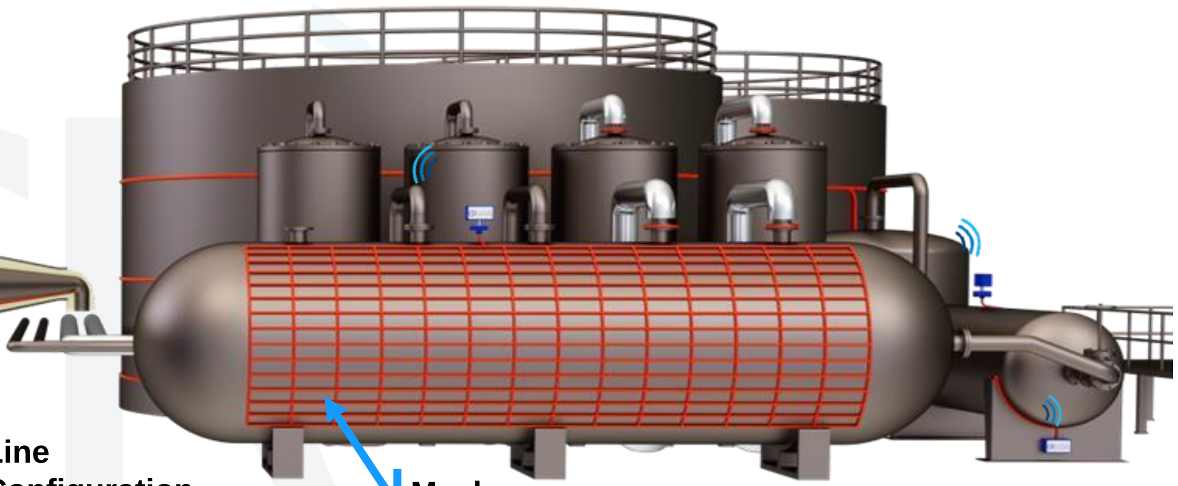




Cloud / On-Premise
Visualisation & Analytics
Dashboard

Unique benefits:

1. Long Range / Spatial coverage
2. Flexible & Easy Deployment
3. Decision management



CR Node (electronics)

ATEX/IECEx Certification	II 2 GD Ex db IIB+H2 T3-T6 Gb Ex tb IIIC T85°C - T150°C Db
Ingress Protection	IP66
Power Source	Mains (24 VDC) / Long life Battery
Temperature Range (°C)	- 20 to +60 °C
Communications	Wireless: Wi-Fi/Cellular/WirelessHART/LoRa Other options: USB
Approx. Dimensions (mm):	284H X 245W X 169D (Without Antenna)
Approx. Weight	11.2 Kg

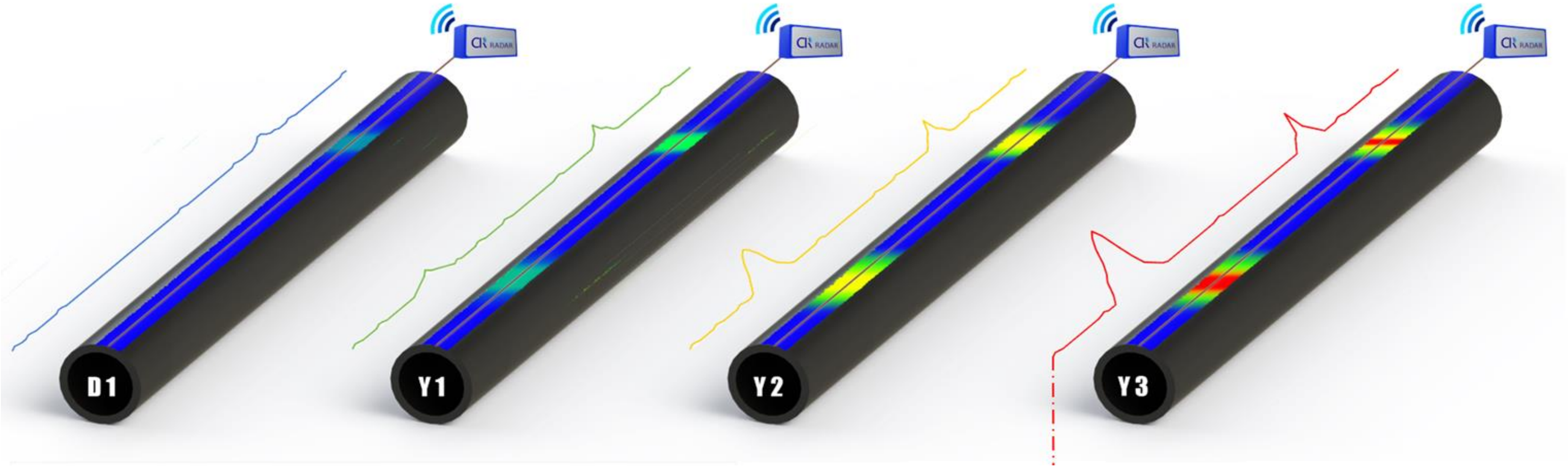
Sensors

Sensor Types	Corrosion Moisture
Sensor Length	Up to 100 m
Temperature Range (°C)	- 190 to +300 °C

Electro-Magnetic Guided Radar (EMGR)

CORE SENSING PRINCIPLE FOR CUI MONITORING

Wave reflection time-of-flight locates the corrosion on sensor

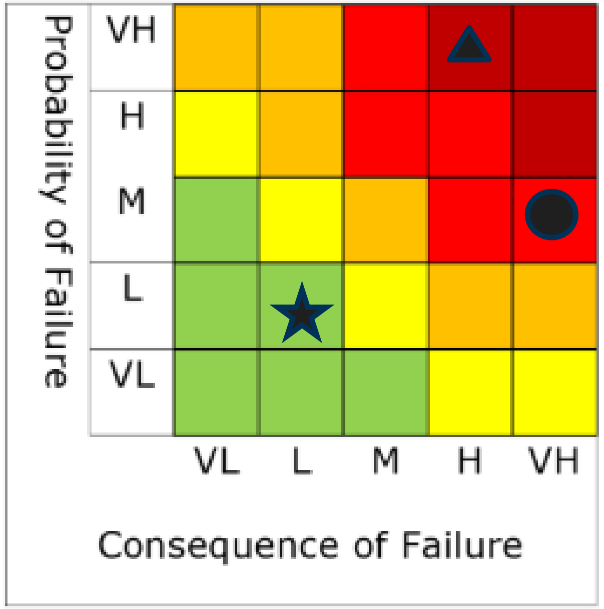


Recent Award
Corrosion 2021
MP Innovation of the year

Dynamic Risk Assessment for CUI

Optimizing Inspections and Safety

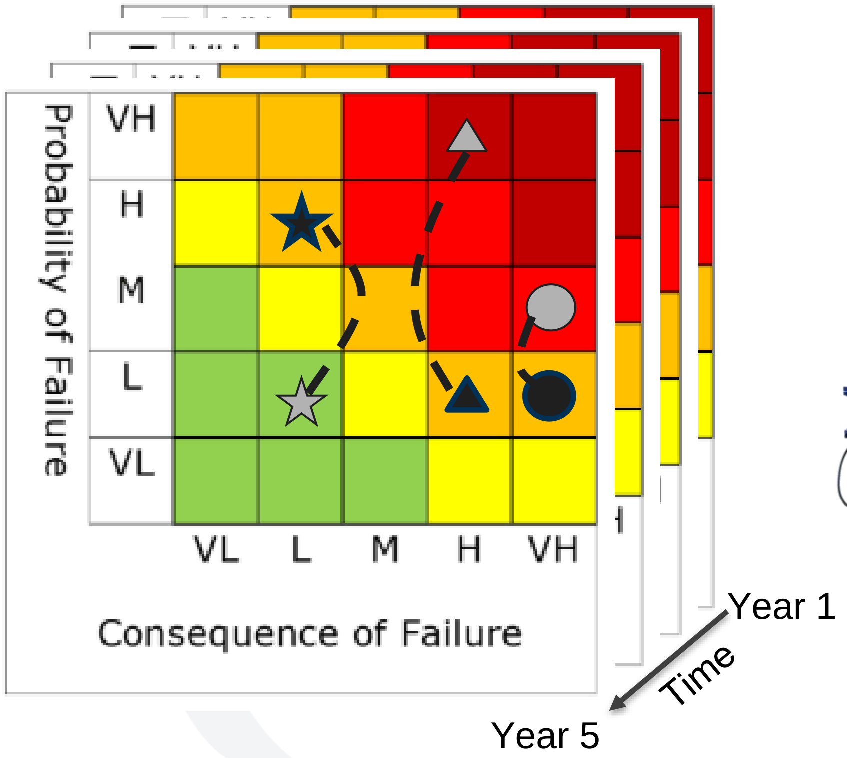
Static RBA



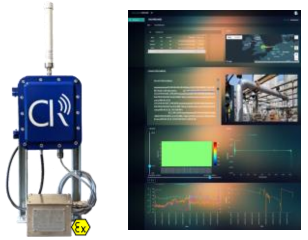
Year 1 ~ Year 5

- Is not periodically updated
- Does not reflect field conditions
- Scope for optimisation

Dynamic RBA



Enabled by CorrosionRADAR monitoring system



- Periodic updates (manual or automated)
- Incorporates field conditions (moisture) e.g. API 581
- Optimised inspection cycles

Localisation for Optimised Inspection Scoping

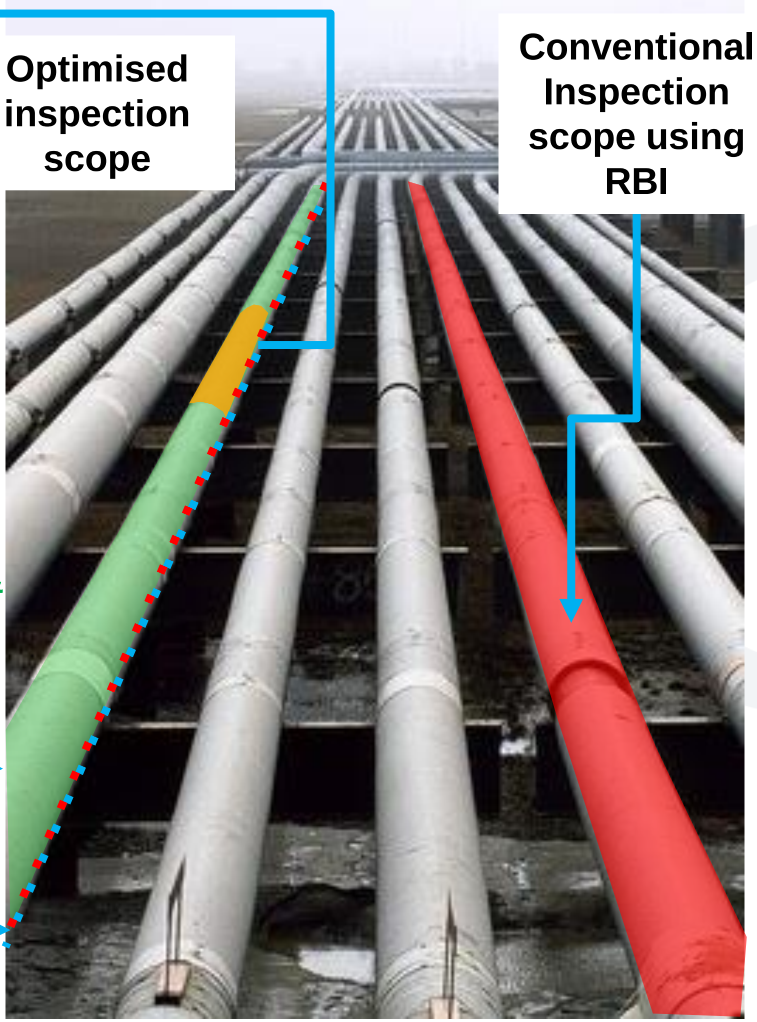
EXAMPLE OF INTEGRATION OF CR TECHNOLOGY WITH CUI ASSESSMENT BASED ON API 581

Avoid over-inspection

RBI - API 581

Optimised inspection scope

Conventional Inspection scope using RBI



Targeted & condition based inspection

100% visual inspection planned

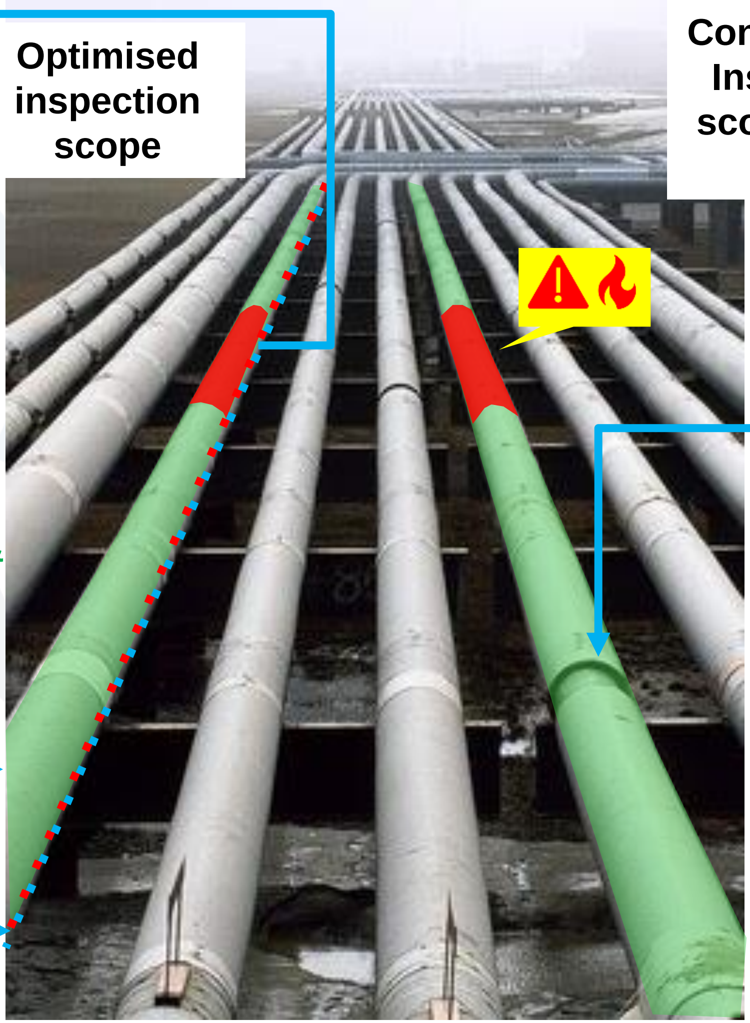
Avoid under-inspection

Determine actual condition based on sensor data

RBI - API 581

Optimised inspection scope

Conventional Inspection scope using RBI



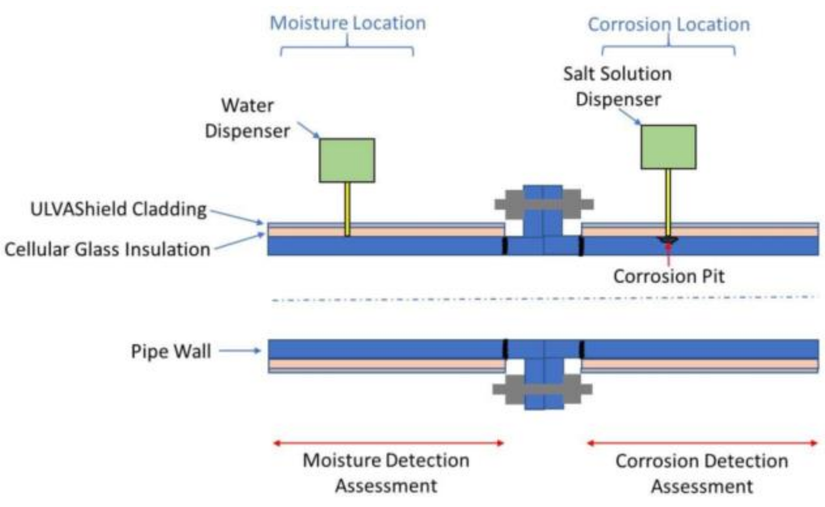
Targeted & condition based inspection

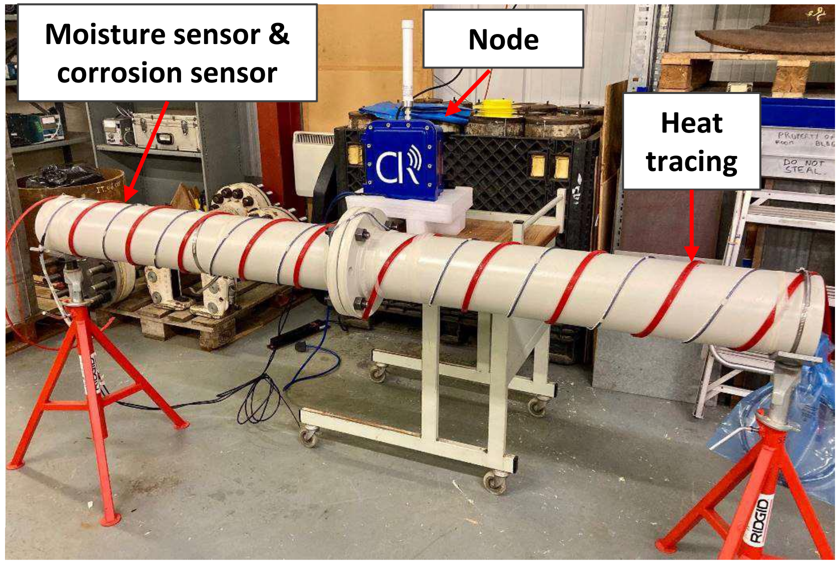
No planned inspection

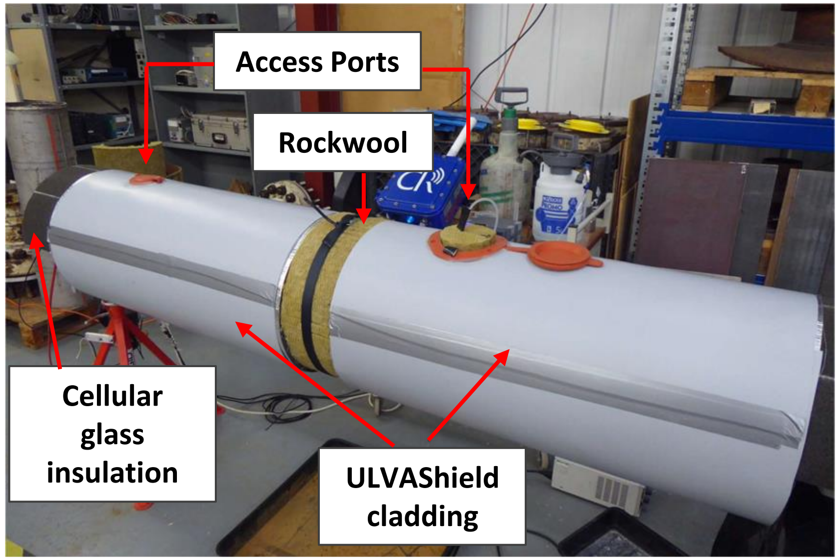
CR Moisture & Corrosion Sensors

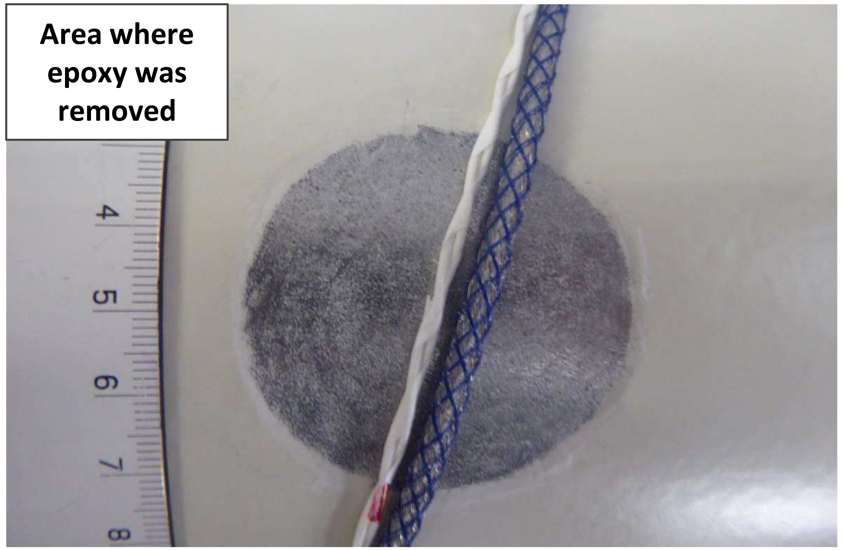
Case Study A

CUI Risk monitoring independent trials by NZTC UK









Case Study A

Net Zero Technology Centre
Technology Driving Transition

CUI RISK MONITORING INDEPENDENT TRIALS BY NZTC UK

Deploy

System Installation
Hardware and Software

Monitor

Remote Monitoring
Detection and Localisation

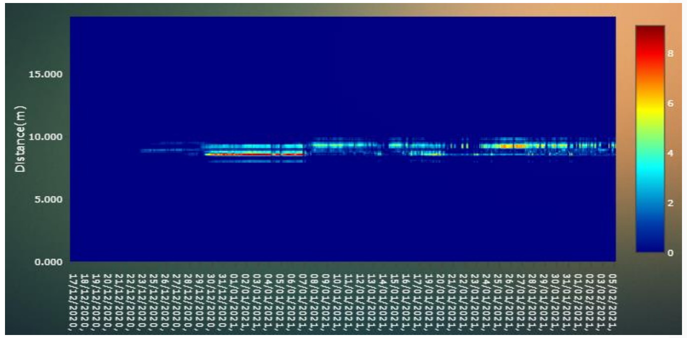
Predict

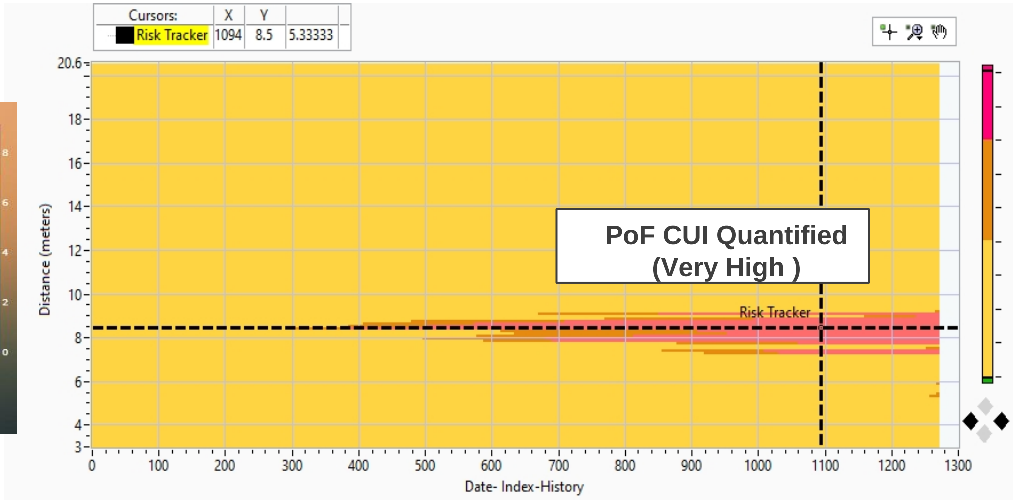
Risk Analytics
Software modules

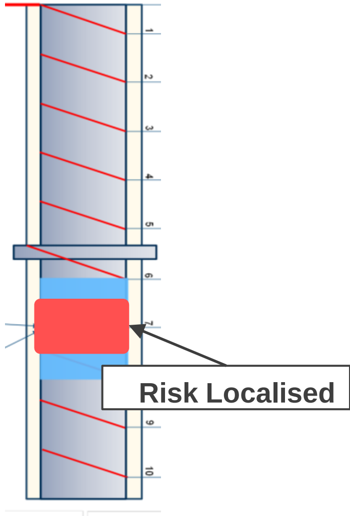
Act

Inspect and Repair
Predictive Maintenance

PoF CUI and PoF CUI barriers				
CUI	COAT	MAT	WAT	DES
VH	VH	M	VH	M

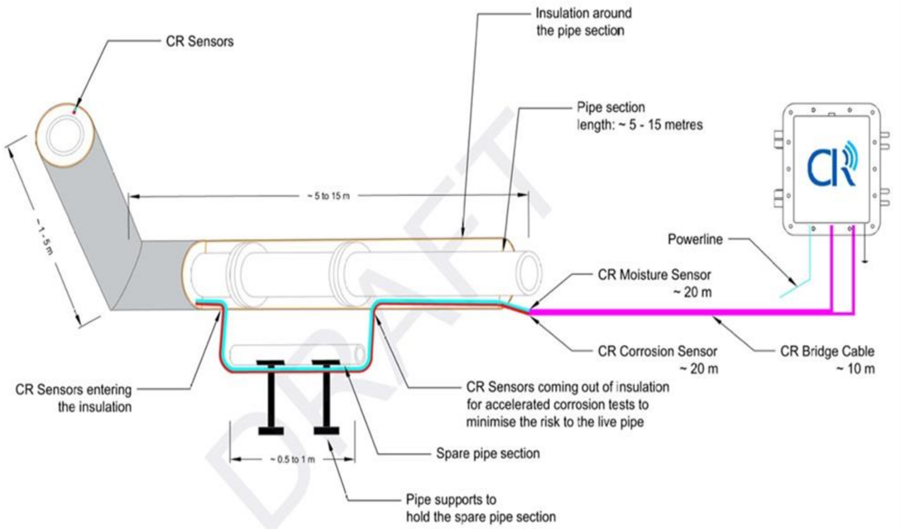


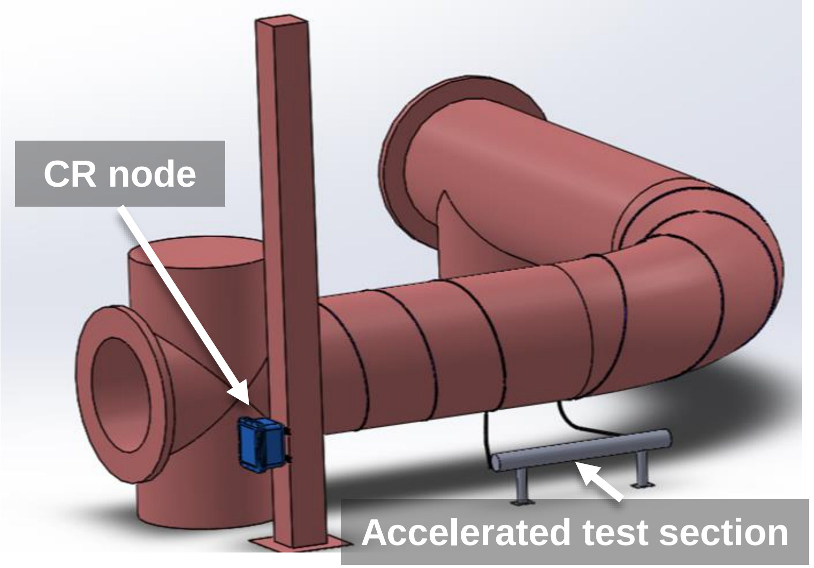


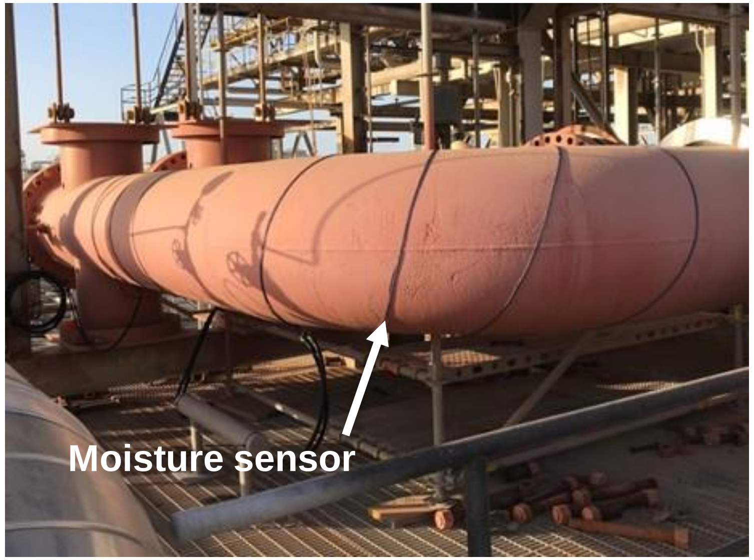


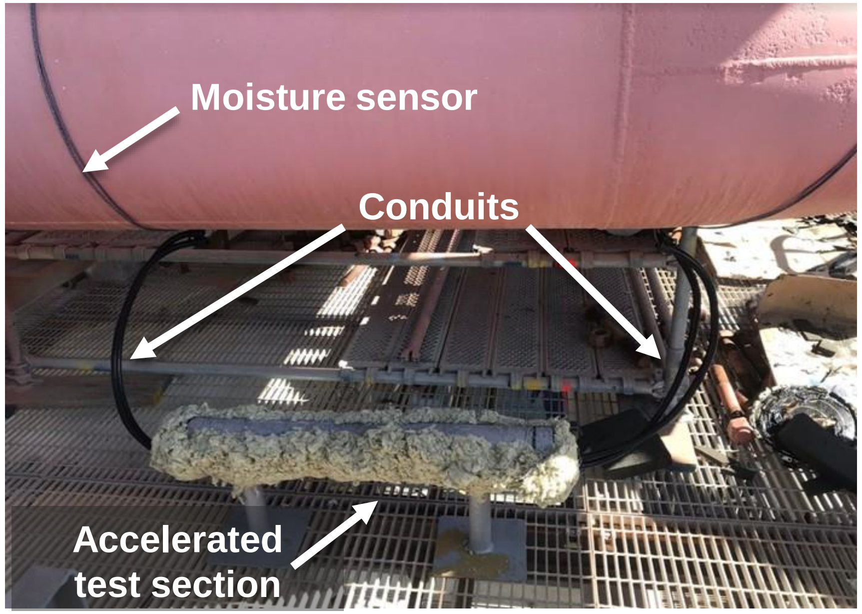
Case Study B

Dynamic Risk Assessment LPG pipeline in arid climate in Saudi Arabia









Case Study B

Dynamic Risk Assessment LPG pipeline in arid climate in Saudi Arabia

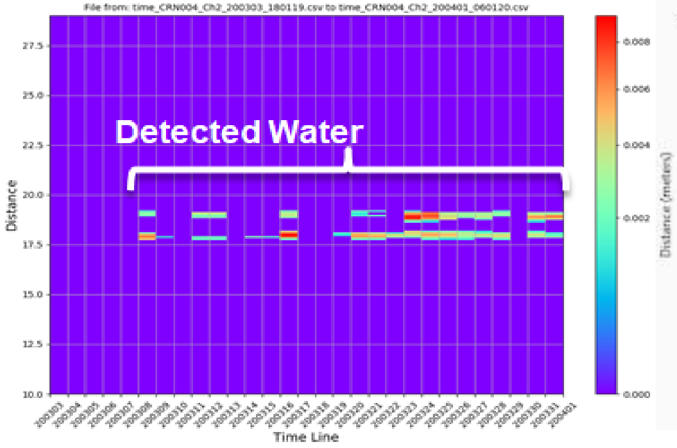
Deploy — **System Installation**
Hardware and Software

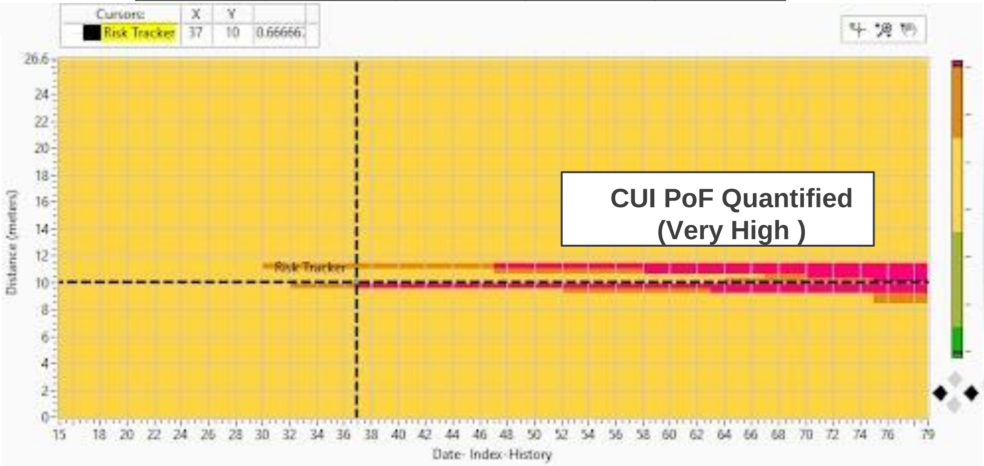
Monitor — **Remote Monitoring**
Detection and Localisation

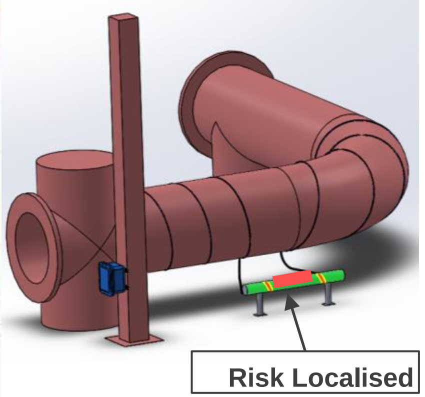
Predict — **Risk Analytics**
Software modules

Act — **Inspect and Repair**
Predictive Maintenance

PoF CUI and PoF CUI barriers				
CUI	COAT	MAT	WAT	DES
VH	VH	M	VH	M

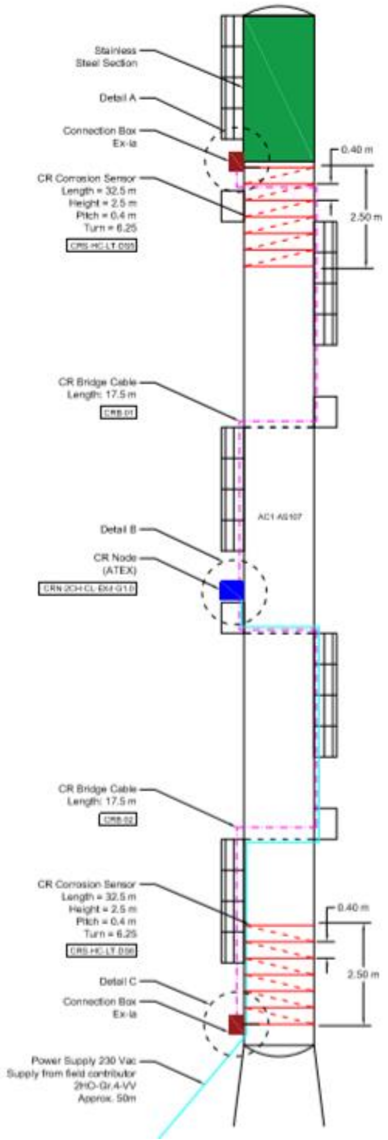


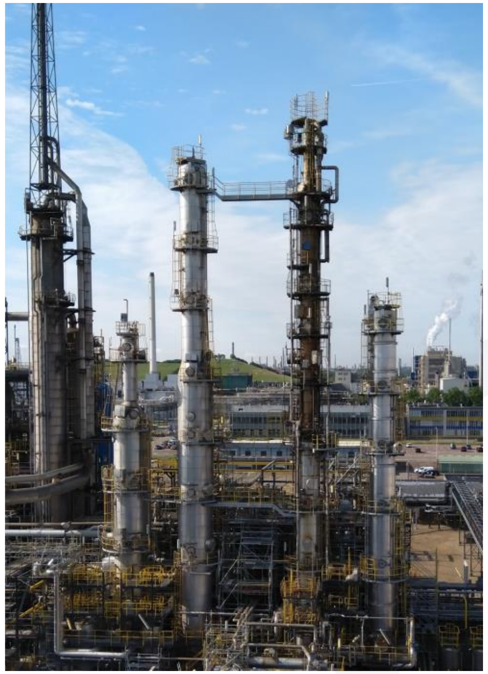




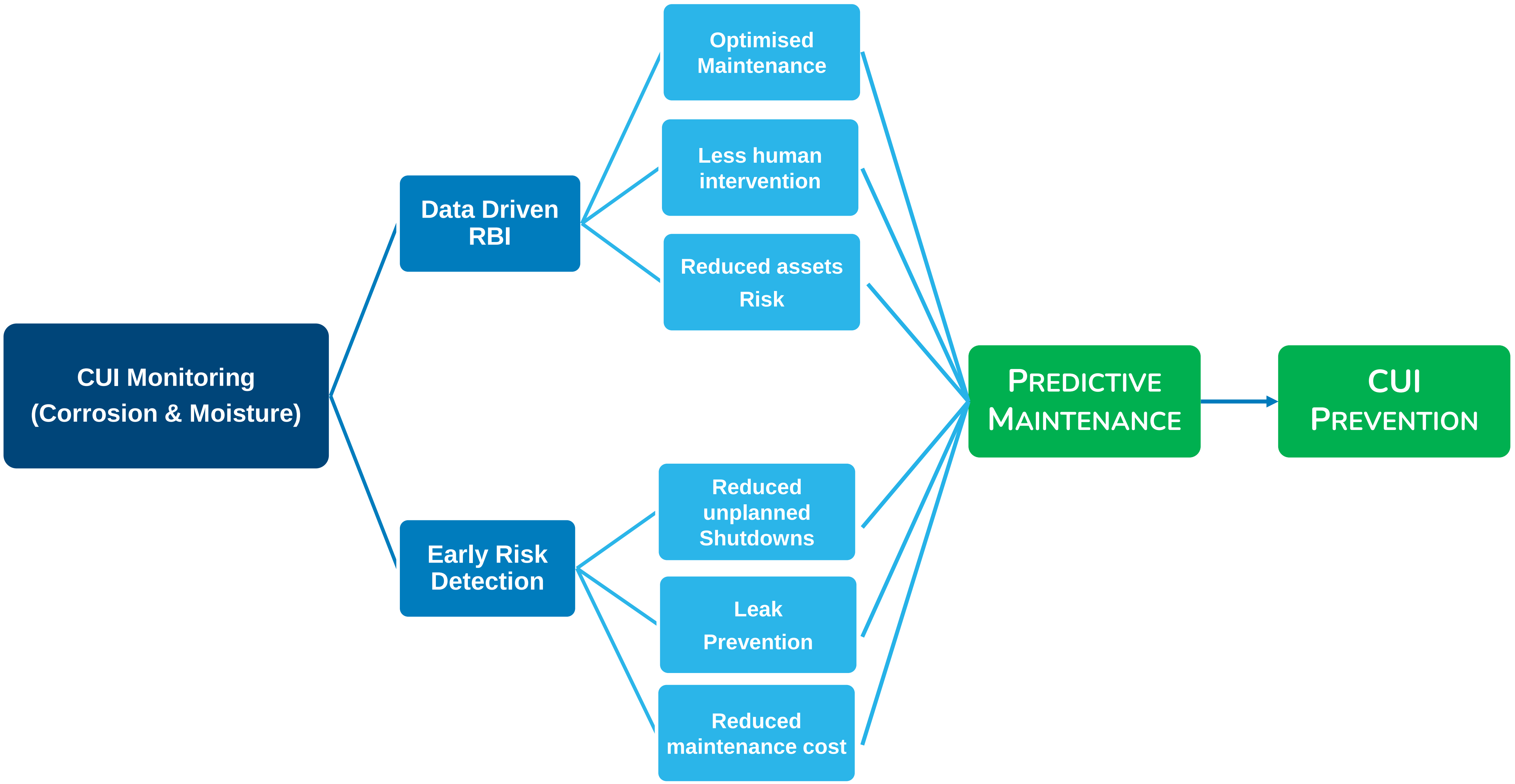
Case Study C

PRODUCTION COLUMN CORROSION MONITORING (ATEX)





Summary – Predictive CUI Monitoring



Online Risk Monitoring of Corrosion Under Insulation (CUI)

info@corrosionradar.com

Thank You

Q & A

Appendix 8

Influence of Painting & Insulation Quality on CUI Behaviour

(Piet van Dooren)

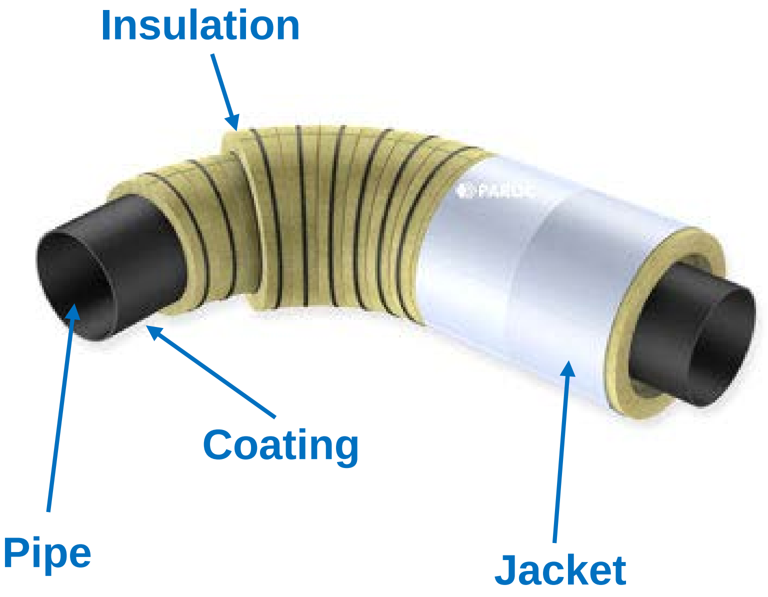
CUI – Corrosion Under Insulation
Influence of Coating & Insulation Quality on CUI Behaviour

Piet Van Dooren
Borealis

EFC WP15 – 23-09-2021

BOREALIS
Keep Discovering

CUI – Corrosion Under Insulation
Influence of Coating & Insulation Quality on CUI Behaviour



Dry Pipe = no CUI

WATER BARRIERS :

- Jacket
- Coating

CUI – Corrosion Under Insulation

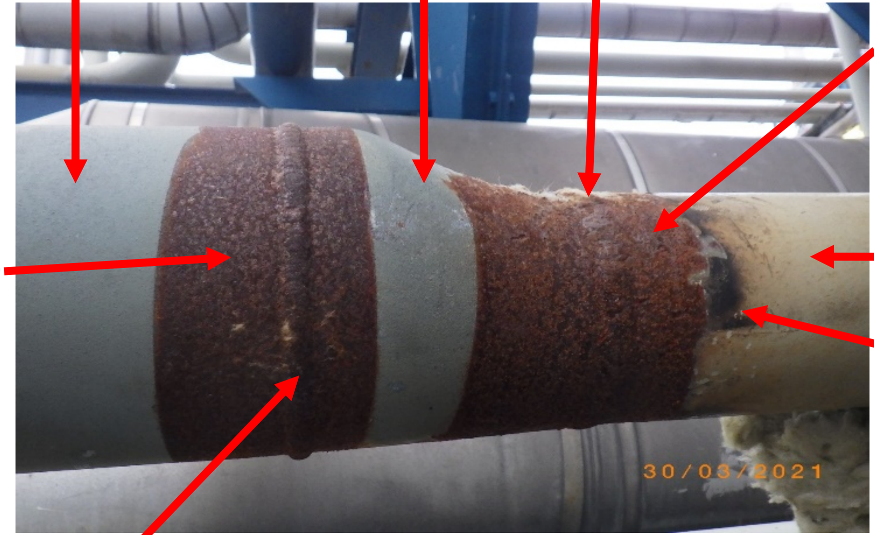
Influence of Coating & Insulation Quality on CUI Behaviour

Same grey paint at both sides of weld

Field Weld

Area unpainted (both sides of weld), to allow for visual inspection during hydrotest

Area ‘masked’ for painting (both sides of weld), to allow for visual inspection during hydrotest



White paint

White paint burned

Prefab Weld

Dry Pipe = no CUI

After pressure test : no painting, immediately insulated

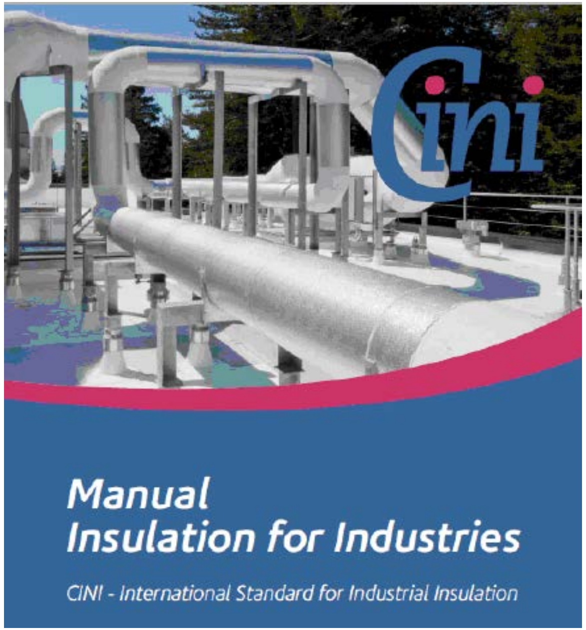
After 20+ years of service : only slight surface corrosion on unpainted areas, paint in good condition ➔ moisture has been kept out well !

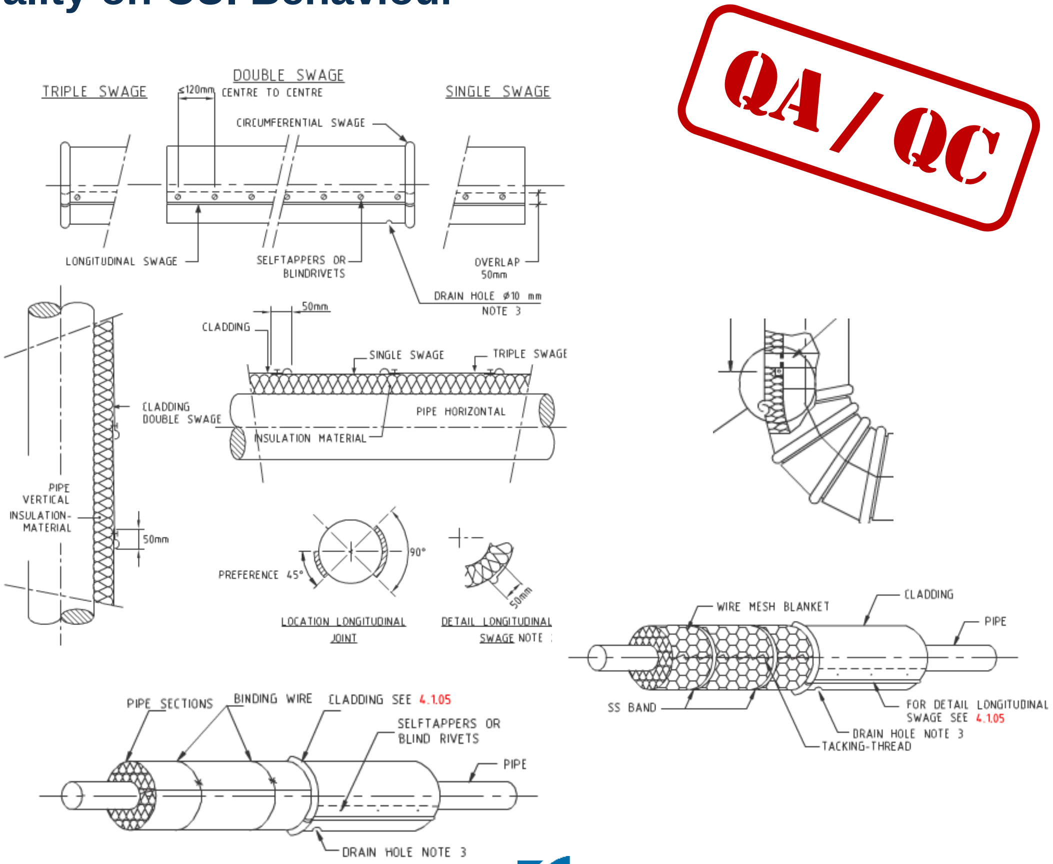
CUI – Corrosion Under Insulation

Influence of Coating & Insulation Quality on CUI Behaviour

Insulation & Jacket details

CINI Manual





CUI – Corrosion Under Insulation

Influence of Coating & Insulation Quality on CUI Behaviour

Insulation & Jacket details

QA / QC

Dry Pipe
= no CUI

CUI – Corrosion Under Insulation

Influence of Coating & Insulation Quality on CUI Behaviour

Painting – Coating – Surface Protection

THE LAST LINE OF DEFENSE !

1. Correct surface preparation ! (usually sandblasting to SA 2,5)

NECESSARY FOR GOOD ADHESION OF COATING

2. Correct coating system / specification
   - Prefer immersion-type coatings
   - TSA ?
3. Correct application of coating :
   - Time between surface preparation & coating
   - Temperature / humidity
   - Film thicknesses
   - Drying / curing times
4. Quality Control & Inspection

QA / QC

CUI – Corrosion Under Insulation

Influence of Coating & Insulation Quality on CUI Behaviour

Painting – Coating – Surface Protection

THE LAST LINE OF DEFENSE !

- Pre-painted straight pipe : paint damaged by bending
- Electrical Heat Tracing : brings temperature right into CUI range
- Severe CUI damage after < 10 years of operation
- Detected in time by RBI (Risk Based Inspection) process and CUI strategy

QA / QC

CUI – Corrosion Under Insulation
Influence of Coating & Insulation Quality on CUI Behaviour

Vents, Drains, Instrument branches, ….

- Usually small bore (< 2” piping)
- Insulation + weather cladding difficult to install & keep watertight
- Often “site-run” installation of piping – no prefab
- Surface Protection often “forgotten”, skipped or uncareful surface protection
- Small wall thickness / quickly “consumed”

QA / QC

EXTRA HIGH RISK FOR CUI

BOREALIS

Influence of Coating & Insulation Quality on CUI Behaviour

QA / QC

Quality program / QA – QC :

- QA = Quality Assurance : assure that **right things are done**
  ➔ procedures & specifications & best practices

- QC = Quality Control : check that **things are done right**
  ➔ checks & inspections (in shop & on site)

To be applied for new plants & projects,
as well as for maintenance, turnarounds, replacements !

➔ Get the basics First Time Right

➔ Keep in good condition

➔ ? Lifetime Expectation ?

CUI – Corrosion Under Insulation
Influence of Coating & Insulation Quality on CUI Behaviour

1. Experiences how to bring QA-, and especially QC-programs in practice ? (coating in shop + on site, insulating, jacketing)

2. Coating degradation : expectations on coating lifetime ?

3. Experiences with ‘contact-free insulation’ ?

Appendix 9

How lower toxicity new yellow metal corrosion inhibitor with high stability improves corrosion performance in recirculating cooling water systems

(Valerie Bour-Beucler)

How lower toxicity new yellow metal corrosion inhibitor improves corrosion performance in recirculating cooling systems

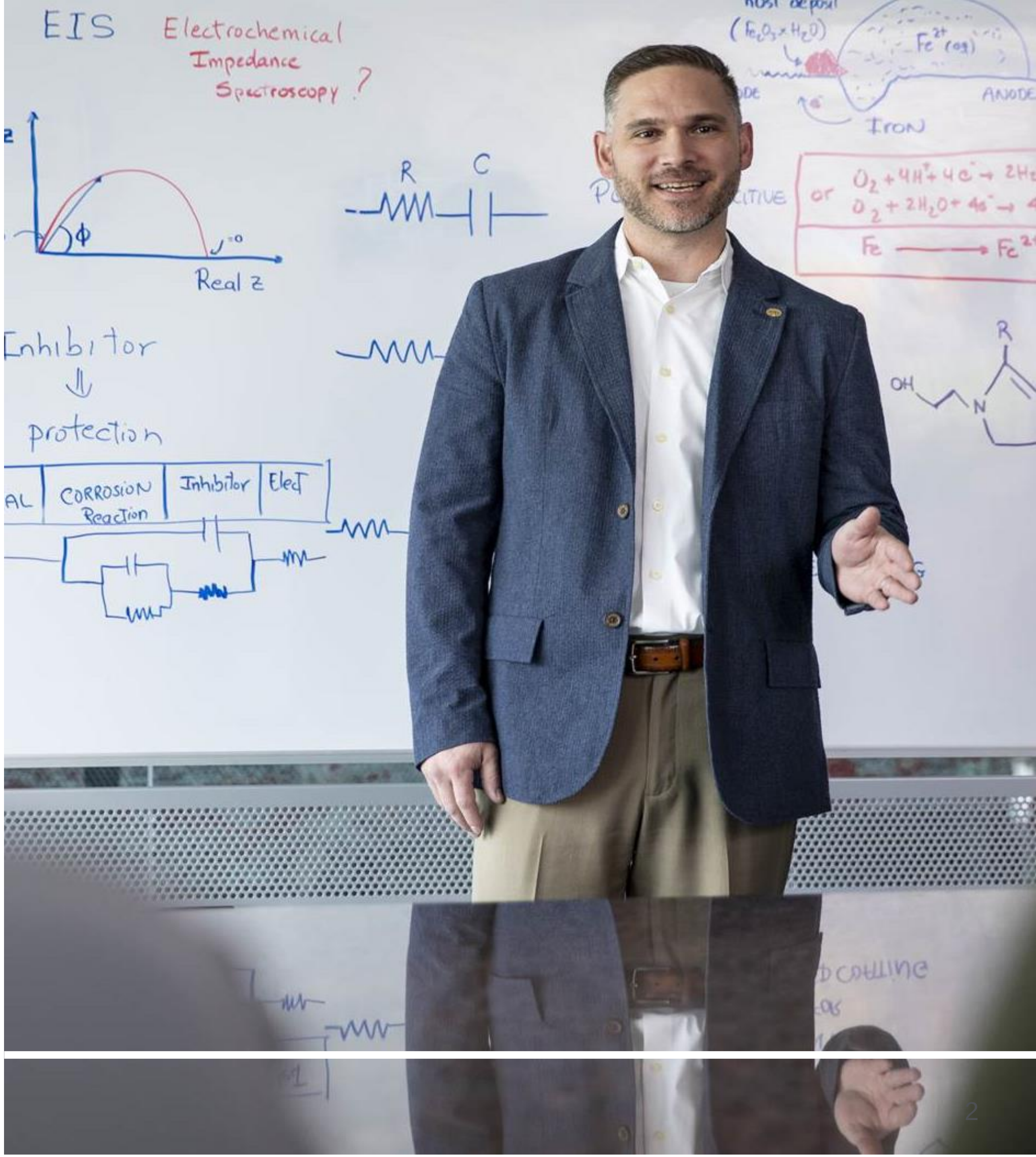
EUROCORR 2021

Valerie Bour Beucler

NALCO Water
An Ecolab Company

AGENDA

- Introduction
- Cooling water corrosion and copper corrosion inhibitors
- Future copper corrosion inhibitor
- Yukon 3DT398 Case studies
- Questions



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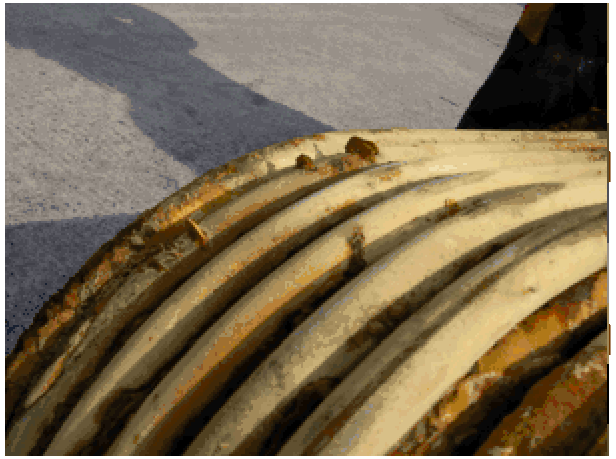
Large recirculating cooling systems

- Refineries
- Petrochemical plants
- Chemical plants
- Power plants

- Heat exchangers metallurgy, condensers…
  - Copper alloys, copper, stainless steel, carbon steel …
- Oxidizing biocides to have bio under control
  - Bleach, gaseous chlorine, mixed oxidants, bromine treatments, chlorine dioxide ….
  - FRC (Free Residual Chlorine)



Copper and copper alloys corrosion and copper release (discharge).

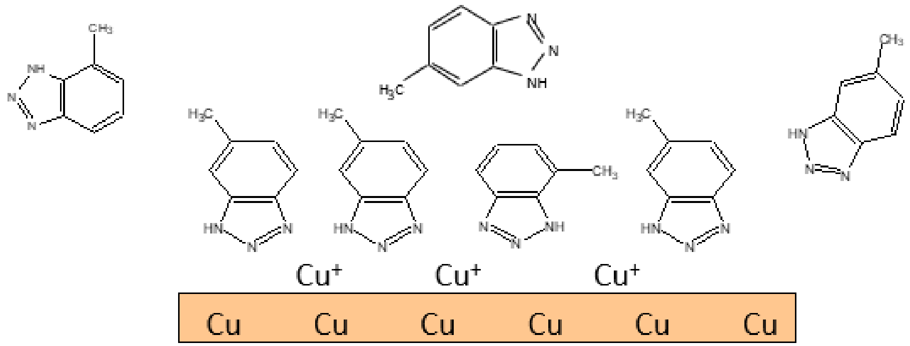
- Galvanic corrosion on carbon steel

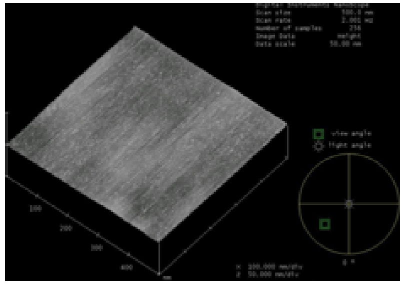
Iron fouling

Life time of heat exchangers
Total cost of operation

Copper corrosion inhibitors

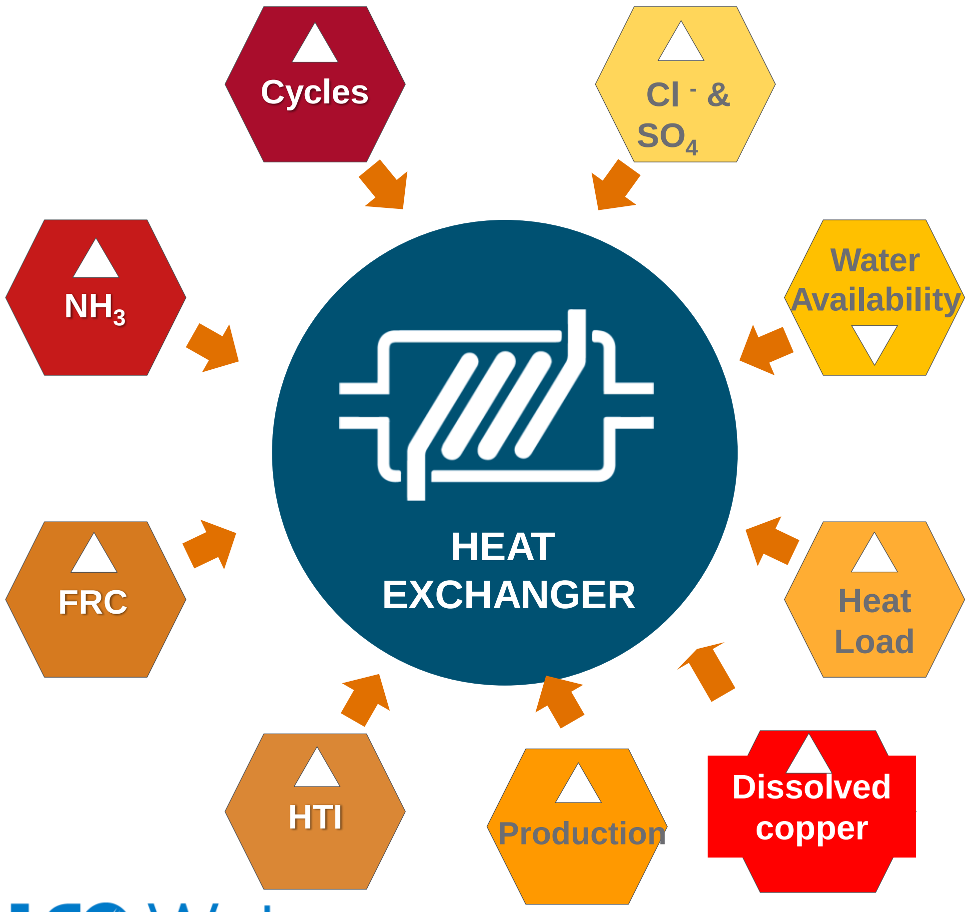
- Commodity azole chemistry (TT, BZT…)
- Filming corrosion inhibitor
  - Surface, residual measurement
- Regulation
  - TOXICITY
  - AOX
- FRC stability
- Copper release (CS galvanic corrosion and discharge)





Corrosion in Critical Heat Exchangers

Stressors



Risks

Increased corrosion potential resulting from more aggressive water composition

Commodity triazole chemicals are **not protecting well at high chlorination** in corrosive high stress waters

Market **demand for lower ecotoxicity** in chemistries

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New challenges….Regulation…..cost control….performance

CHALLENGE *Aggressive biocontrol practices & poor cooling water quality increase asset integrity risk and corrosion stress on critical yellow metal heat exchangers.*

INCREASED RISK PROFILE

- *Asset failures*
- *Plant down time*
- *Safety & health*

TOXICITY

PERFORMANCE

NALCO Water
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New yellow metal corrosion inhibitor

YUKON 3DT398

ENHANCED PERFORMANCE

REGULATORY COMPLIANCE

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The Future of Yellow Metal Protection

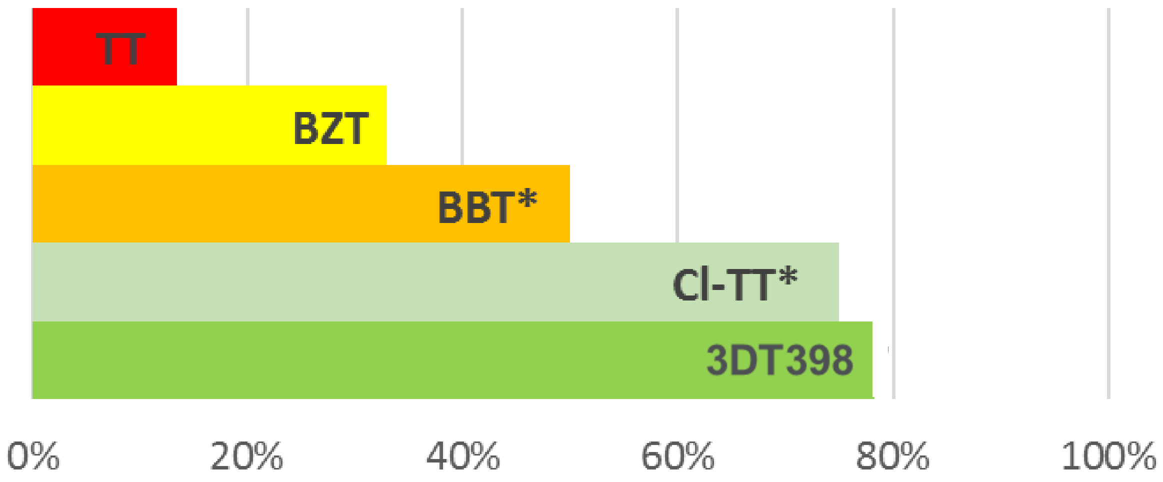
Robust Film-Forming Inhibitor	▶ ***Reduces corrosion by up to 5x*** across various water chemistry conditions
Best-in-Class Halogen Stability	▶ ***Outperforms triazoles*** for wider operating windows with lower consumption rates[1]
Non-Toxic to Aquatic Life	▶ ***Lowers ecotoxicity impact*** to fish and invertebrates
Odor-Free in CTs	▶ ***Effective with aggressive chlorination*** in cooling towers
Instant, Safer Analytics	▶ ***Improves results accuracy by 10x*** with safer method
Manufactured In-House	▶ ***Mitigates market volatility*** and supply insecurity
Exclusive Technology	▶ ***Three patents pending*** on innovative solution

[1] In typical cooling water with Halogen stress and/or low pH (Average free chlorine at 0.5 ppm; pH 7.5)

Best in Class Halogen Stability

New yellow metal corrosion inhibitor is Halogen Stable in Bleach, Stabrex, Brominated Biocides and ClO2

- ✓ Commodity azoles, TT and BZT degrade in the presence of halogens



Inhibitor Residual in the Presence of Halogen *estimated

Test Method:
pH 8.2, Temp 32 degree C
Initial active inhibitor 5ppm
0.5ppm continuous biocide residual control;
Duration: 4 hours
Copper metal immersed in water

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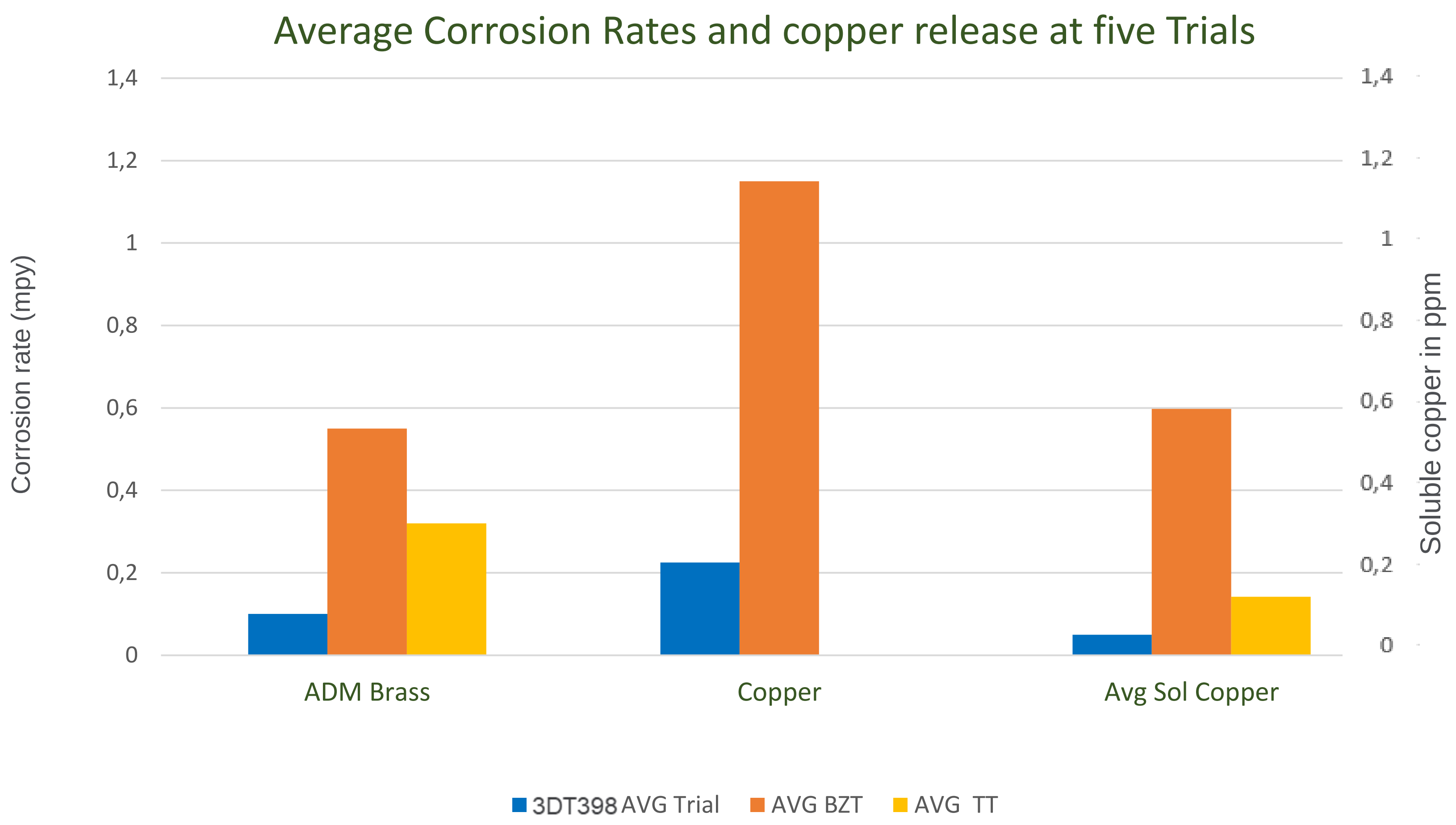
An Ecolab Company

Lowest Corrosion Rates and copper release

New yellow corrosion inhibitor improved corrosion rates and reduced soluble copper release to water



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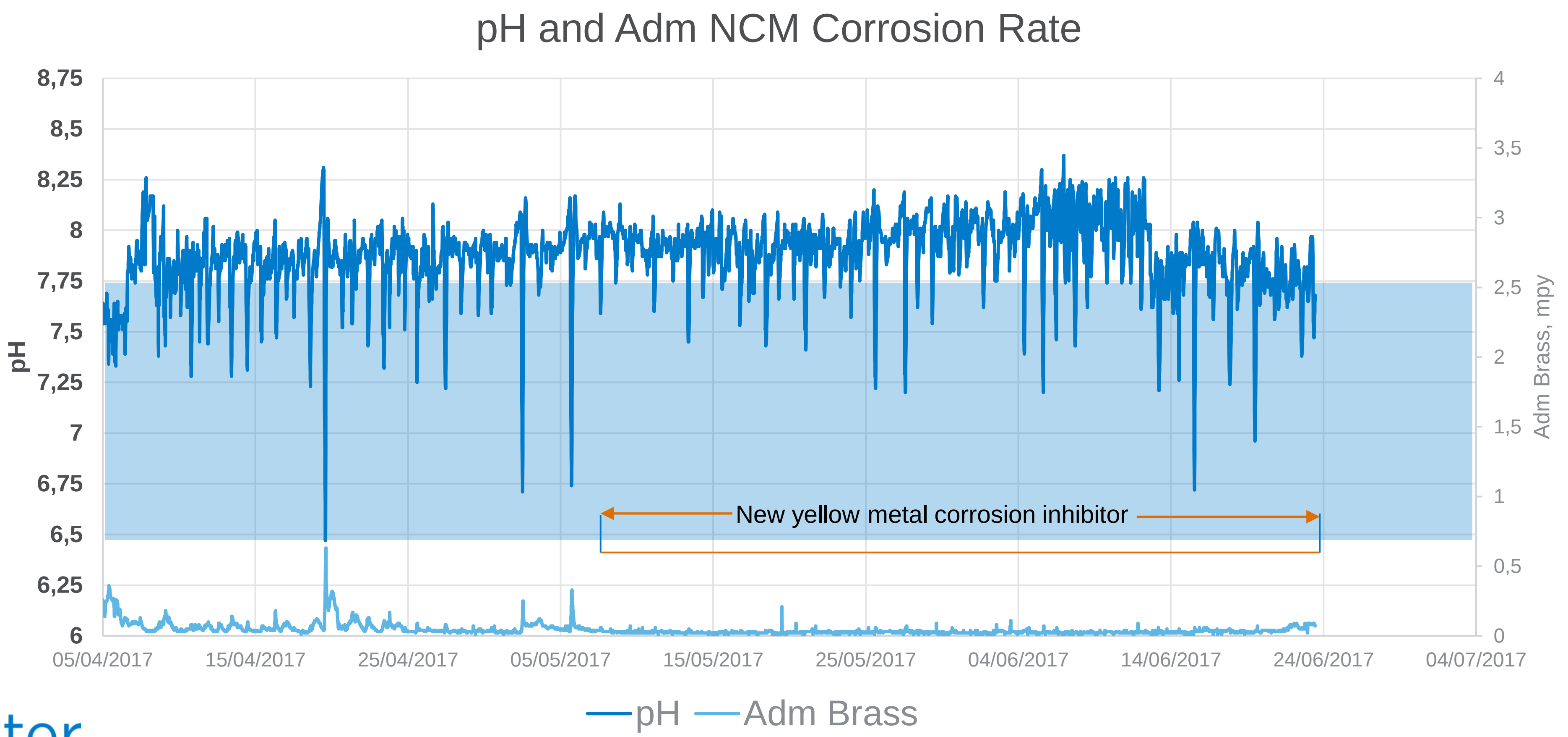
Low pH has minimal effect on Corrosion and Cu Release

- Low corrosion rate was maintained during pH drops down to ~6.
- Soluble Copper was kept below 30ppb during the trial.



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Comparative Performance Superior to Commodity Triazoles

Delivering Performance

> **More persistent in solution;** *not susceptible to chlorination*

> **Up to** *5x thicker film* **on copper / brass surfaces**

> **Robust film** *protects against aggressive water chemistries*

KPIs	**YELLOW METAL CORROSION *NEW INHIBITOR***	**TT**	**BZT**	**BBT**	**CL-TT**
Cooling System Corrosion Protection	⊕	◑	◔	●	◕
Film Thickness	⊕	◑	◔	TBD	◕
Ecotoxicity	⊕	◑	◑	○	◔
Chlorination Resistance	⊕	◑	◑	●	◕
Odor in Cooling System	⊕	◔	●	●	◕
Analysis Speed and Accuracy	⊕	◔	◔	◔	◔

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Yukon 3DT398 Benefit

PRODUCTIVITY

ENHANCED PERFORMANCE

- Superior tolerance to halogens - stability
- Robust corrosion control
- No odor

WATER

WATER SAVINGS

- Water Savings with increased cycles

WASTE

REGULATORY COMPLIANCE

- Less hazardous than commodity azoles
- Lower toxicity to aquatic organisms
- Reduced soluble copper discharge
- Reduced AOX discharge

ASSETS

ASSET PROTECTION

- Lower corrosion rate
- Extended Life of Heat Exchanger

COSTS

TCO DELIVERED

- Reduced corrosion rate
- Precise measurement of residuals to ensure proper dosage
- Heat exchanger efficiency improvement

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CASE STUDY

CH-2103 3DT398 Technology Reduces Corrosion and Environmental impact at Power Plant

eROI℠ by Ecolab

INSIGHT

- Azole-based corrosion inhibitor to protect Cu:Ni condenser.
- high concentrations of organic material in the make-up water results in high chlorine demand and bleach and bromine dosage.
- Free Residual Chlorine (FRC) was about 0.2 ppm
- The FRC degraded the performance of the azole. The result: high copper corrosion rates and copper concentrations in the plant outfall.
- Corrosion threatened the integrity of the plant's condensers.

INNOVATION

New, non-toxic halogen stable corrosion inhibitor 3D TRASAR® Technology for Cooling

ANNUAL SAVINGS

ASSETS

Reduced copper corrosion

-75%

ENVIRONMENTAL RESPONSIBILITY

Reduced copper discharge

- 60% Cu

Corrosion Rate (mpy)	BZT	3DT398
Admiralty Brass	0.4	0.1
Copper	1.7	0.1
Cu:Ni 70:30	0.1	0.02
Cu:Ni 90:10	0.2	0.02

Table 2. Corrosion rate before and during trial with Yukon

Water Chemistry	BZT	3DT398
Active Feed (ppm)	0.80	0.47
Active Residual (ppm)	0.12	0.37
Loss of Inhibitor (%)	85%	21%
Avg soluble copper (ppm)	0.15	0.06

Table 3. Water Chemistry before and during trial with Yukon

BEFORE

DURING

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MidWest Refinery Using TT

Challenge: High corrosion due to high chlorination

Before with TT	***After*** Yellow Metal Corrosion Inhibitor

- Unclarified surface water as make-up; TT used
- Corrosion improvement under agressive chlorination practices ***due to manual bleach feed adjustment***
- 0.7 ppm FRC +/- 0.7 ***(often exceeding 2.5 ppm)***

Recirculation Water	Baseline	YMCI Average
Chloride mg/l	214	214
Sulfate mg/l	754	792
Calcium as CaCO3 mg/l	480	587
pH	7.8	7.9
Conductivity mS/cm	2257	2557
FRC mg/l Cl2	**0.74**	**0.83**
Inhibitor Consumption	**93% (TT)**	**25%**

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Chemical Plant

Challenge: Copper corrosion metric challenging at high HTI

Before with BZT	***After*** Yellow Metal Corrosion Inhibitor
▪ 90% of heat exchanger surface area is copper ▪ Copper ***corrosion KPI not met*** ▪ 0.2 - 0.5 mpy typically, target metric < 0.1 mpy ▪ ***High soluble copper levels*** > 180 ppb. Winter HTI > 15 days, more than 2x longer than summer operation ▪ ***TT supplement*** to base BZT feed	**New inhibitor staged over 60 days and eliminated TT altogether for the final 30 day coupon:** ▪ 2:1 TT : ***New inhibitor coupon to 0.2 mpy*** (NCM probe flatlined at 0.01 mpy) ▪ 1:1 TT : ***New inhibitor coupon to 0.1 mpy*** ▪ 100% new technology ***kept coupon at 0.1 mpy*** ▪ ***Soluble copper dropped*** from 180 ppb to 100 ppb

Asia Pacific Chemical Plant

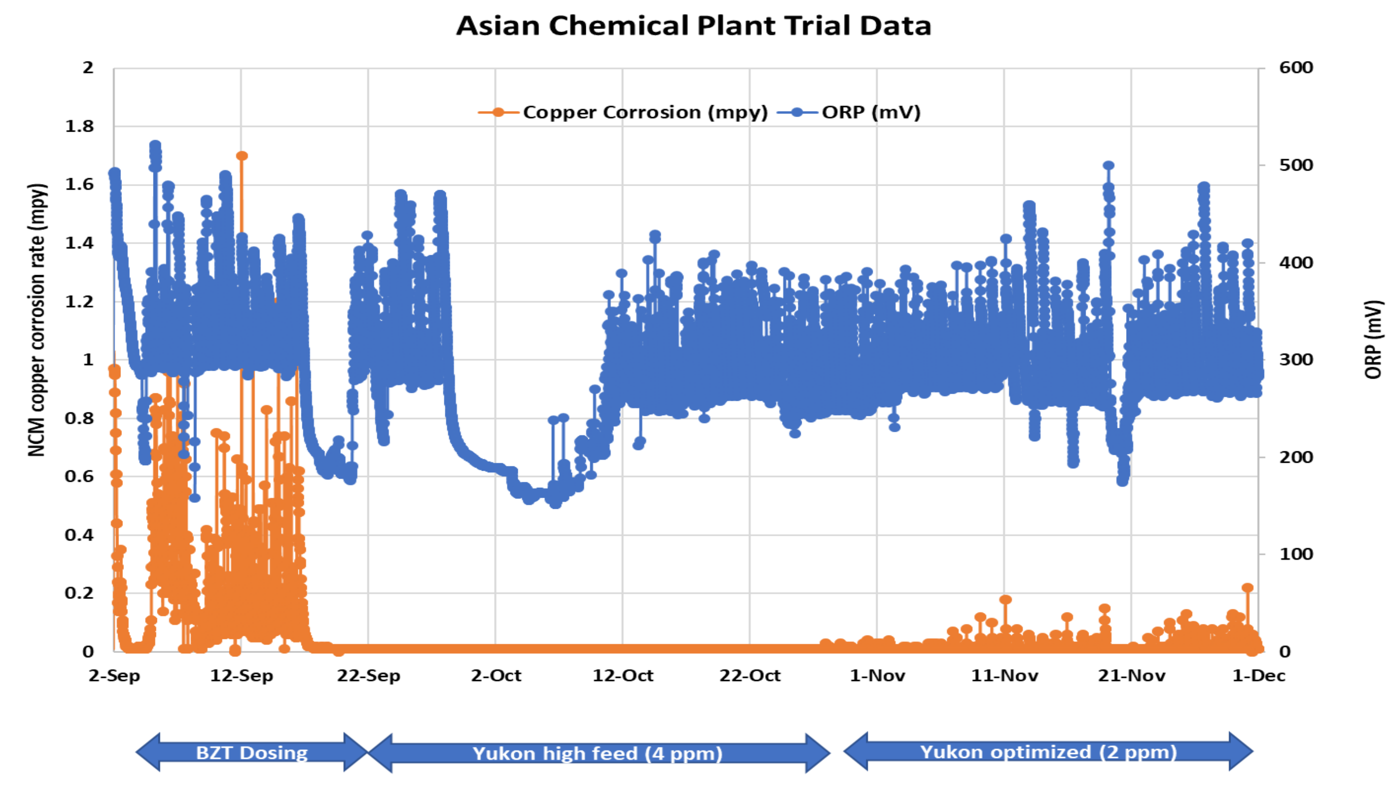
Challenge: Softened water as make-up (MU), high cycles

Before with **BZT** | ***After*** Yellow Metal Corrosion Inhibitor

- ***Low hardness*** (8-10 ppm), 300 ppm Sulfate, 200 ppm Cloride
- Coupon corrosion ***0.6 mpy & 0.7 mpy with BZT*** on Copper & Brass
- BZT found to degrade 50% under ***0.4 ppm FRC chlorination***
- ***1000 ppb soluble copper*** lingering in cooling system at 10-15 cycles

AFTER with YMC INHIBITOR

- Coupon corrosion ***0.1 mpy***
- ***60 ppb soluble copper***



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Appendix 10

The utilization of thermal spray cladding systems to locally address preferential corrosion in existing cladding systems - Preferential corrosion of weld seams or HAZ in higher nobility CRA cladding systems

(Colin Bateman)

“The utilization of thermal spray cladding systems to locally address preferential corrosion in existing cladding systems ”

SURFACE TECHNOLOGY SOLUTIONS

Colin Bateman, NACE Level 3
Integrated Global Services (IGS)
‘Surface Protection for Mission Critical Equipment’

INTRODUCTION:

- Preferential corrosion in process equipment is typically associated with changes in the substrate metallurgy or environmental conditions which render the local metal to be more susceptible to corrosive attack, these can be due to:
  - Welding or fabrication Heat Affected Zones (HAZ) which have not been adequately Post Weld Heat Treated (PWHT)
  - Fabrication defects in installed cladding systems
  - Termination points of existing cladding systems (e.g. in a column or tower where a cladding is installed by design in the top dome section)
  - Changes to the FEED composition, e.g. different FEED quality (opportunity crudes), contamination (Chlorides entering the process) etc.

INTRODUCTION:

How can we protect an asset from its operating environment?

- *By installing a **Permanent Barrier** to mitigate further metal loss*

- *Providing an **Alloy Upgrade** to internal surfaces*

Utilizing proprietary High Velocity Thermal Spray technologies.

Dissimilar weld corrosion in 60” main feed stainless steel gas lines for major new build major (2.5 bn scfd) gas facility in KSA

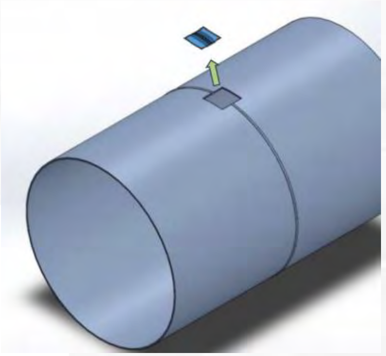
Background

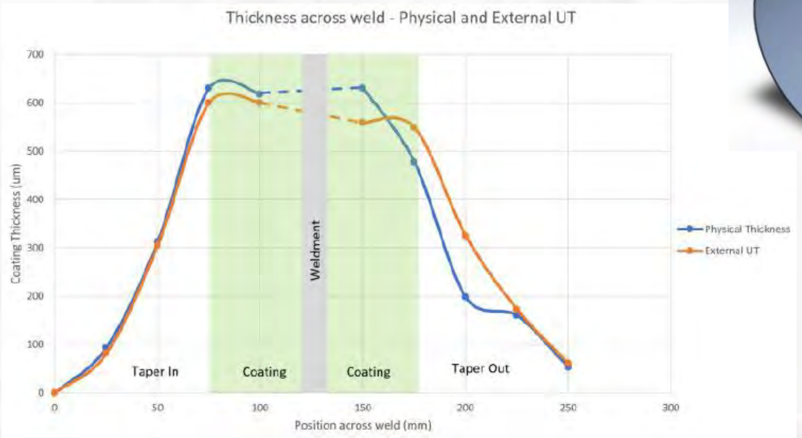
Substrate:
Stainless Steel
Corrosion Mechanism:
In service bimetallic corrosion due to dissimilar welds on the main gas pipe sections.

Project Details

Mockup testing, application (semi-automated) and inspection procedures (laser scanning) tests were completed.

The project was executed by IGS from August 2018 until March 2019





Results

IGS HVTS encapsulated 138 circ. weld lines of spool sections of the main horizontal 60” gas inlet lines.

Restoring the completion timeline and significantly reducing the change management costs.

External ultrasound NDE baselines established for future continuous condition assessment.

Delayed Coker Fractionator Column Project:

- Discovery scope during 2021 shutdown
- Critical corrosion challenge on a high value process asset
- Ageing internal cladding (embrittled) was the key challenge
- HVTS (no HAZ) combined with:
  - IGS Experience (internal client referral from US colleagues)
  - Knowledge (Lab Reports, Testing, Case Studies)
  - Operational capabilities
- Won confidence and closed the project execution

Delayed Coker Fractionator Column

Background

History:

Delayed cokers decarbonize and demetallize heavy petroleum residues to produce fuel-quality by products.

Fractionator has 2 main sections:

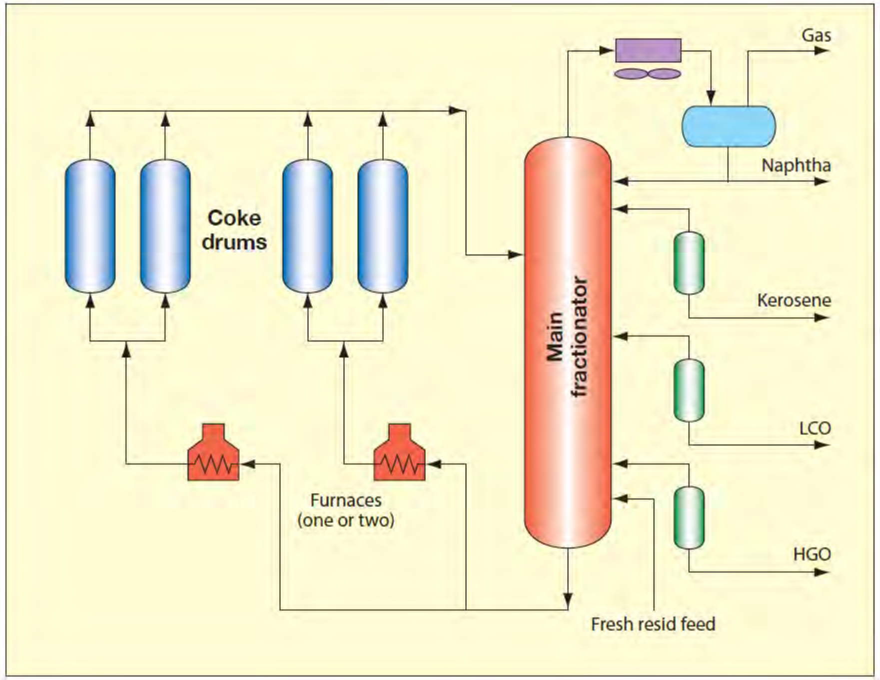
- Upper section = Fractionation Zone
- Lower section = Wash Zone

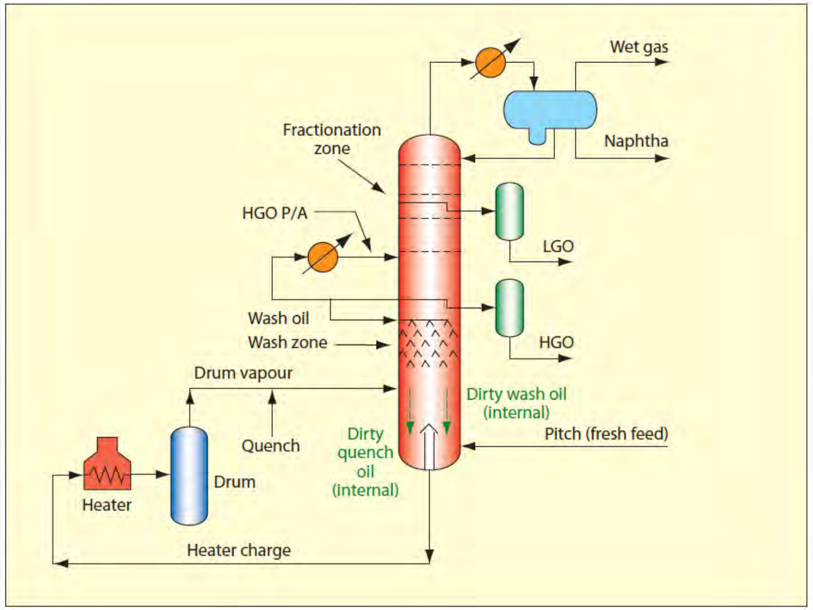
Original column/tower installed in 1970's, internally clad with Type 400 stainless steel. Type 400 cladding has become 'highly embrittled' over time.

Column operates around 700F (370^{o}C) and 40 psig (2.75 bar) and is susceptible to sulfidation and naphthenic acid corrosion.

In 2015 client cut out and welded in a new nozzle insert plate assembly in the column due to localized corrosion.

Due to the cladding cracking risk a band of approx. 50 mm of c/s was left exposed around the plate weld which was subsequently rapidly corroded, meaning a new, larger, plate had to be installed in the 2021 outage.





Delayed Coker Fractionator Column

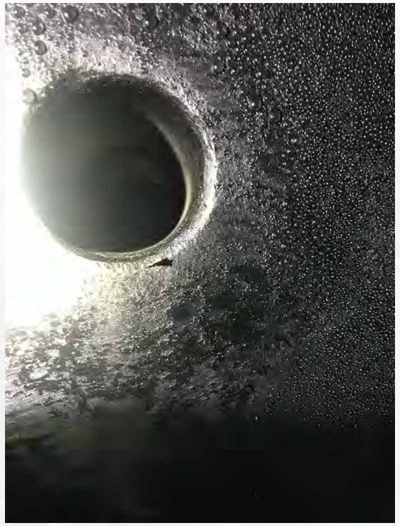
Background

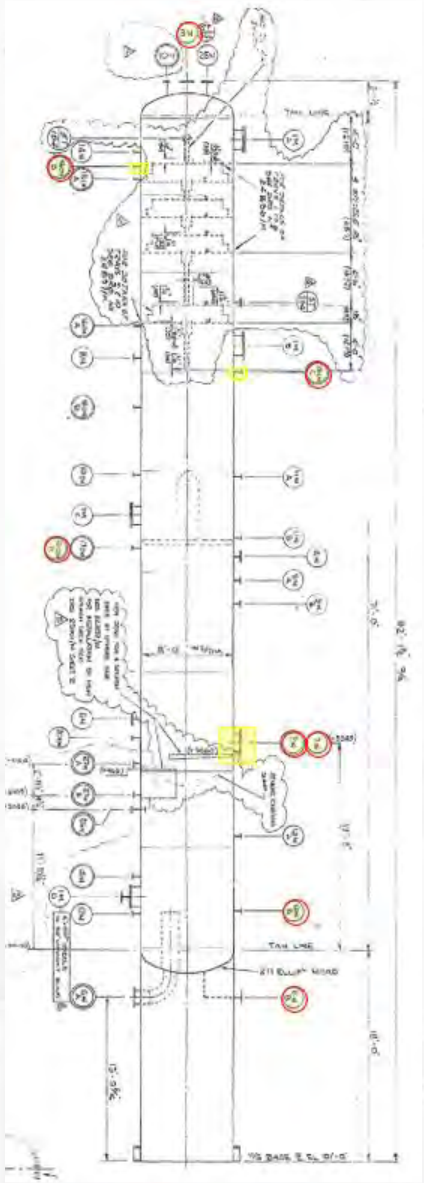
History:

Nozzle plate was redesigned following inspection of the column to a larger size as further cracking was apparent after removal of the existing plate, this was due to stress concentrations caused by previous welding and external reinforcement rings.

These areas required overlaying using carbon steel consumables prior to removal of the insert plate to facilitate the new weld overlay corrosion resistant 2021 Q1 insert plate repair. Repair procedure was to clean area to bright metal and apply a 50°C preheat using a propane flame torch, weld build up corroded areas to nominal thickness of 13mm; on weld completion, grind flush with substrate.

Upon initial inspection by IGS, the edges around the nozzle plate were too sharp and required further dressing back by grinding to remove edges and prevent stress concentrations of the HVTS.





Delayed Coker Fractionator Column

Process Used:
After further grinding and inspection, IGS technicians carried out the surface preparation using grit blasting to prepare the Inconel 625, carbon steel band and surrounding Type 400 s/s cladding to facilitate the application of the IGS HVTS system to bridge the exposed c/s area.

IGS HVTS cladding system was applied at nominal thickness 500 µm (20 mils), on the internal surfaces around the nozzle plate and 2 x nozzles where the client had either replaced existing nozzles or identified localized damage (approx. 1m2 total surface area).

Plate after installation


Plate after surface preparation


Plate after HVTS application

Delayed Coker Fractionator Column

Project Details

Process Used:

Nozzle was replaced in 1985. Nozzle constructed of ASTM A106 Gr. B with INCO 625 weld overlay deposit. A 1/2" band of cladding on the shell (ASTM A263 Gr.0 - Stainless Cr Steel-Clad Plate) was removed around the circumference of the nozzle. The cladding was reinstated following completion of the nozzle replacement and inspection have identified an LTA of corrosion in this reinstated clad area. Grinding local to the repair area prior to cladding commencement.

Nozzle after grinding

Nozzle after surface preparation

Nozzle after HVTS application

Delayed Coker Fractionator Column

Project Details

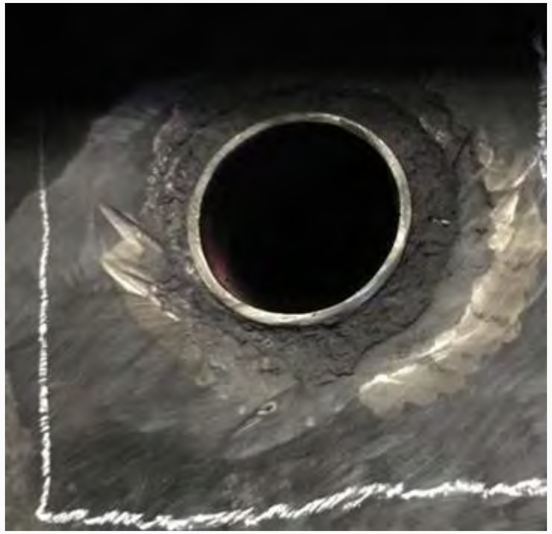
Process Used:

Nozzle was replaced in 1985.

Original shell material to ASTM A263 Gr. 0 specification (Stainless Cr Steel-Clad Plate).

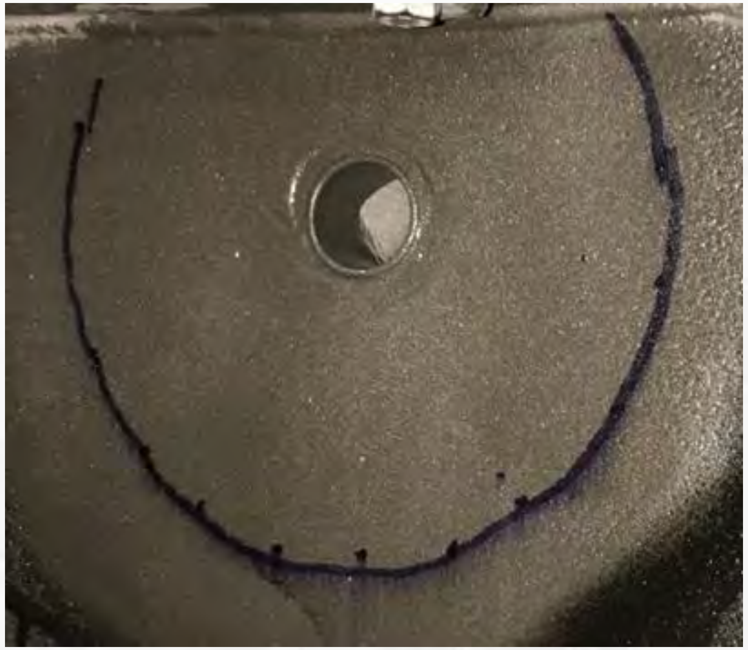
A 1/2" band of cladding on the shell around the nozzle was removed during the repair and it is thought the cladding was either not reinstated or the incorrect filler material has been used and the cladding has subsequently corroded.

IGS HVTS system applied to reinstate cladding up to the nozzle inlet.



Nozzle after grinding

Nozzle after surface preparation



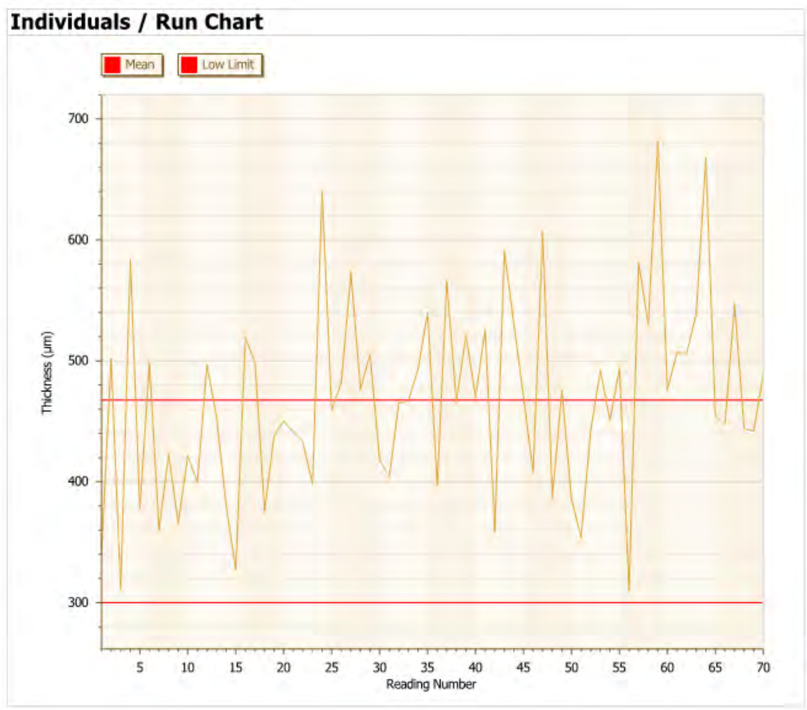
Nozzle after HVTS application

Delayed Coker Fractionator Column

Inspection Results

Process Used:

The final thickness inspection (on carbon steel section only) was done after IGS system cladding application.



Business Results

Client Benefits:

IGS HVTS solved key integrity issue discovered during an outage in a critical process asset, providing a solution for life extension avoiding replacement or major mechanical works.

Statistics	
# Readings	70
Mean	467,59 µm
Maximum	682,0 µm
Minimum	310,0 µm
Standard Deviation (σ)	80,39 µm
Mean + 3σ	708,77 µm
Mean - 3σ	226,41 µm
Coefficient of Variation	17,2%

Limits			
Low Limit	300,0 µm	# Readings Below	0 (0,0%)

HVTS BENEFITS:

- **Fast, in-situ CRA metallurgy upgrade field application:**
  - Reducing field CRA installation time and project timelines
- **No HAZ, no requirement for PWHT:**
  - Will not create HAZ risks or costly and time consuming PWHT
- **Long term, robust, internal corrosion protection of critical process assets:**
  - Providing corrosion protection for the Design Life or the Asset or Life Extension.

REDUCED OPEX AND DOWNTIME DUE TO:

- **Inspection Costs:**
  - HVTS cladding has demonstrated its capability to perform well beyond the typical 4 year inspection cycle, enabling your clients to consider longer inspection cycles.
  - External inspection capability to validate integrity avoids process shutdowns.
- **Reduced Maintenance Costs:**
  - HVTS cladding prevents vessel pressure boundary wastage. Internal pitting and corrosive attack is no longer evident in the assets protected with HVTS.
- **Reduced shutdown/turnaround scope and schedules:**
  - A reliable, robust corrosion barrier enables the plant to plan outages with confidence and practically eliminates unplanned/discovery maintenance scope
  - Long service life of HVTS cladding removes requirement to repair/replace the corrosion barrier or pressure boundary in critical process vessels every turnaround/shutdown.

IGS Turnkey Solutions:

- IGS have over 35 years of site experience delivering turnkey surface technology solutions, working onsite for industry focused on the power, oil & gas, petrochemical sectors
- IGS have an established infrastructure globally, with a local offices, personnel and representation, as well as equipment and materials strategically staged.

Surface Technology Solutions:

"The utilization of thermal spray cladding systems to locally address preferential corrosion in existing cladding systems "

Colin Bateman

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Appendix 11

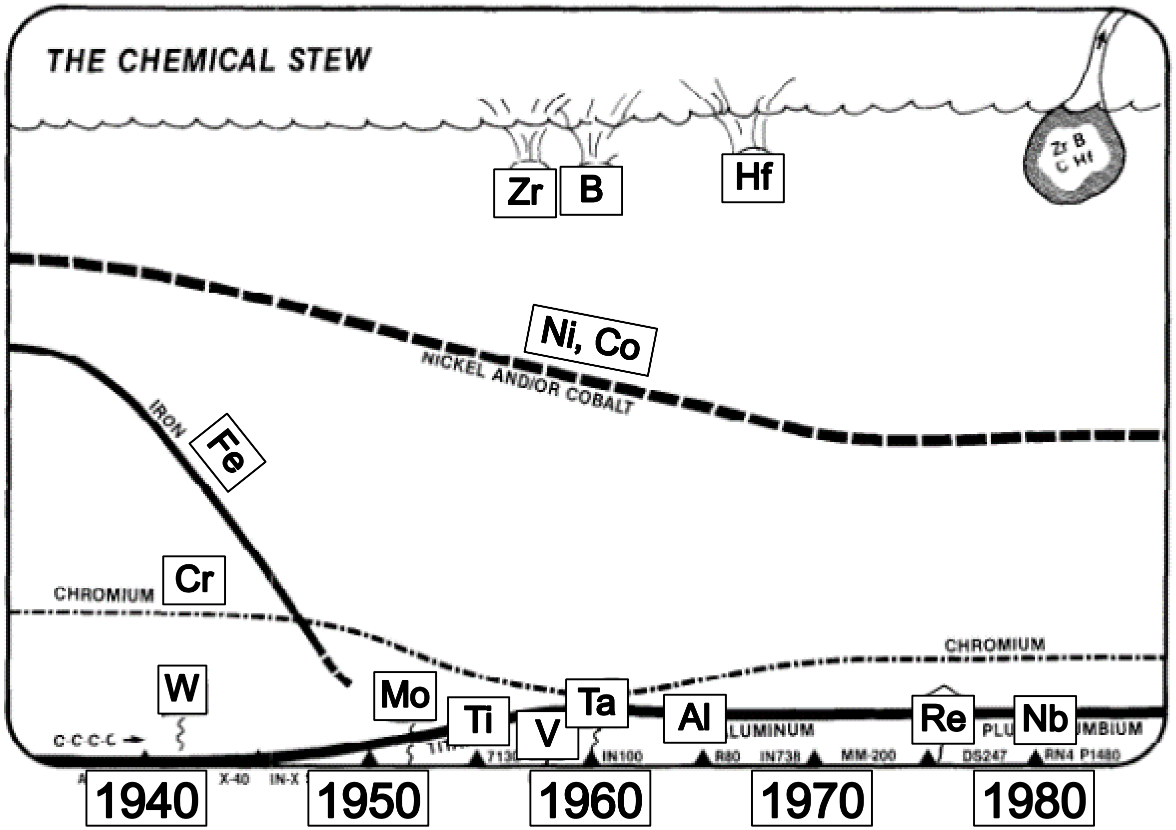
The Oerlikon Rapid Alloy Development (RAD) platform

(Justin Cheney)

The Oerlikon Rapid Alloy Development (RAD) Platform

September 23rd, 2021

Historical Alloy Development



*From A Development of Superalloys for the Superalloy Metallurgists

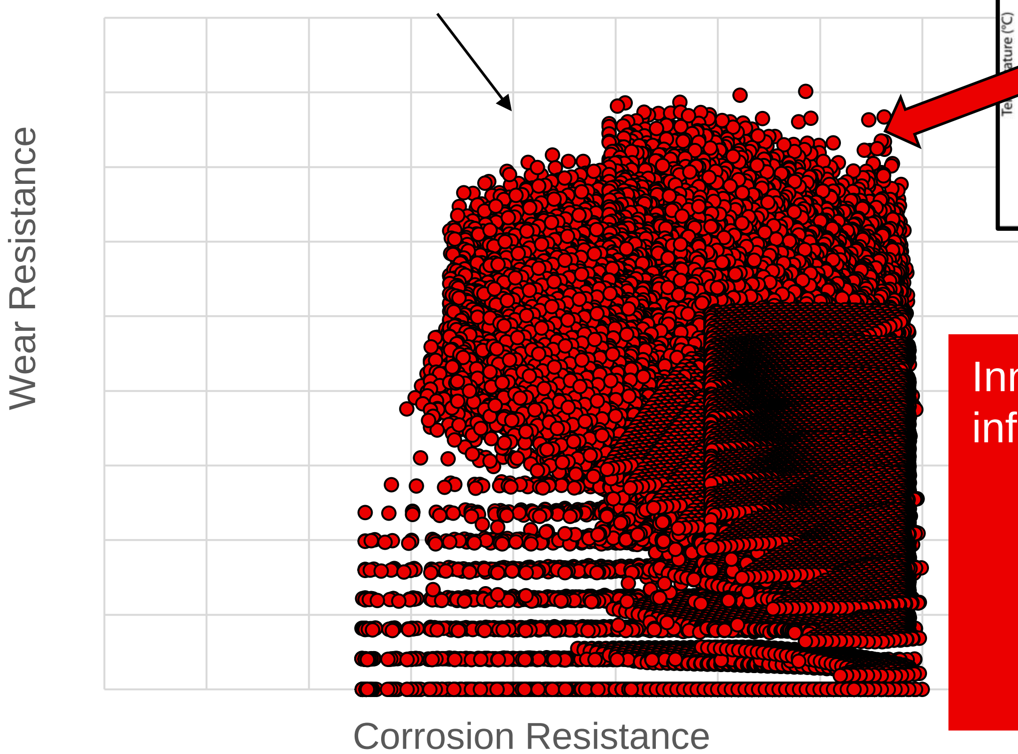
Historically, alloy development took place using purely experimental methods effectively 'trying' a lot of chemistry additions, this method takes time.

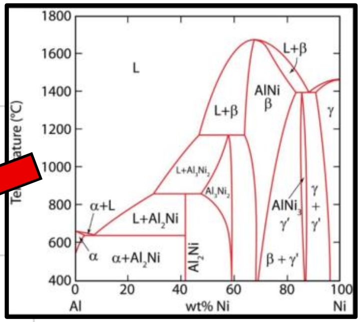
Tomorrow's Innovation Tool

Other properties we commonly model

- Alloy / Manufacturing Cost
- Strength
- Cavitation
- Galling
- Machinability
- Magnetism
- Metal Dusting
- Molten Metal (Al, Zn) Attack
- Carbide Matrix Reactions
- Crack Resistance
- Harmful Element Elimination
- Wear
- Corrosion
- High Temperature Properties
- CMAS Resistance
- Thermal Cycle Fatigue
- Thermal Conductivity…

Each dot represents one alloy



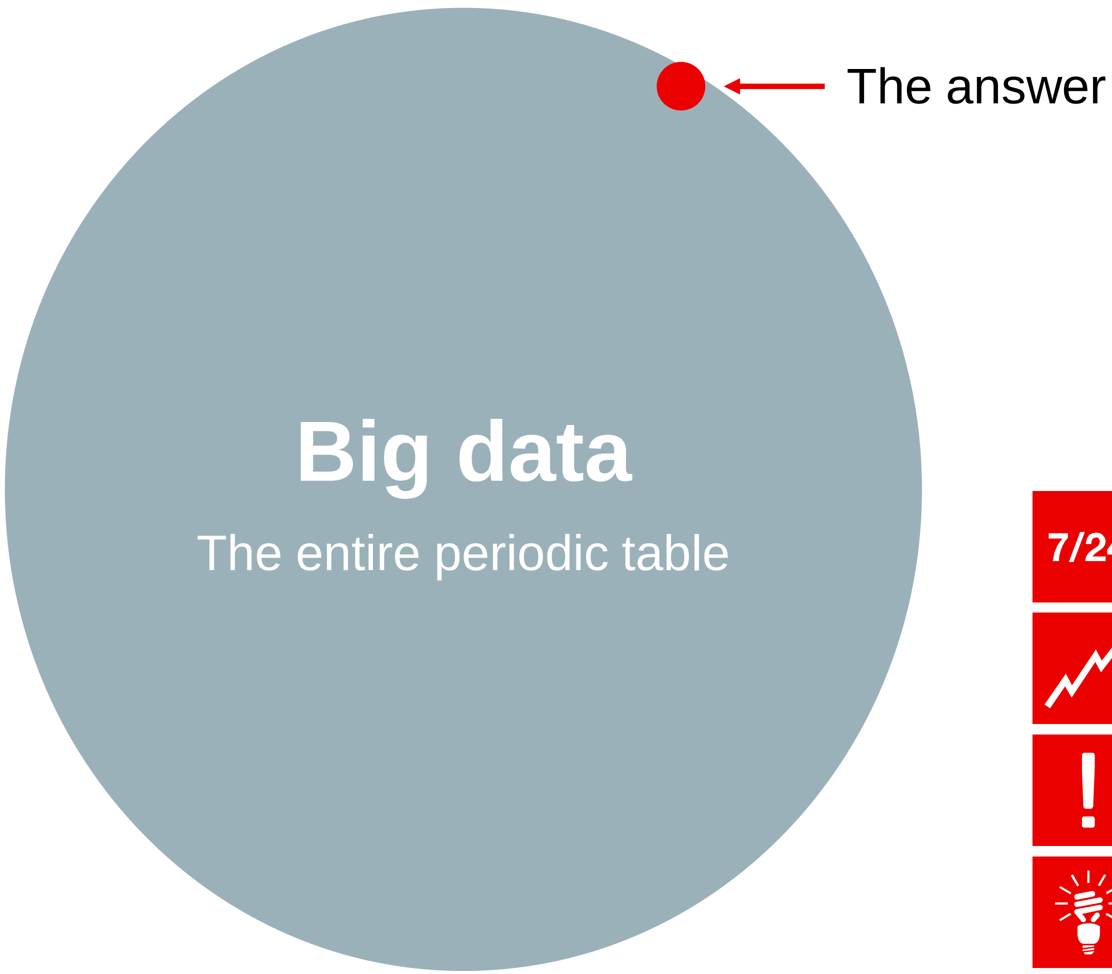


Innovating in infinite dimensions

∞D

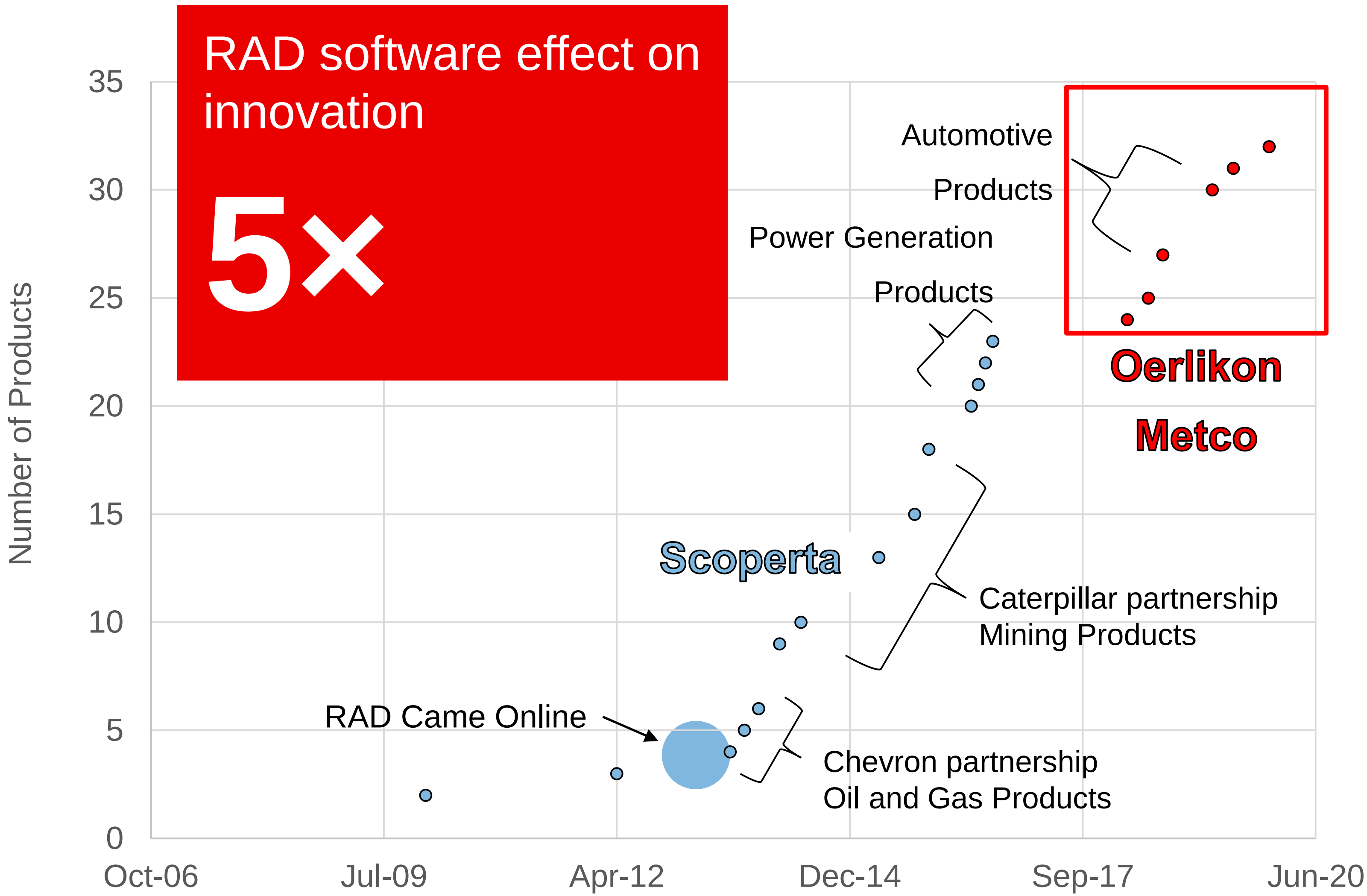
RAD is the Materials Embodiment of Big Data

oerlikon metco

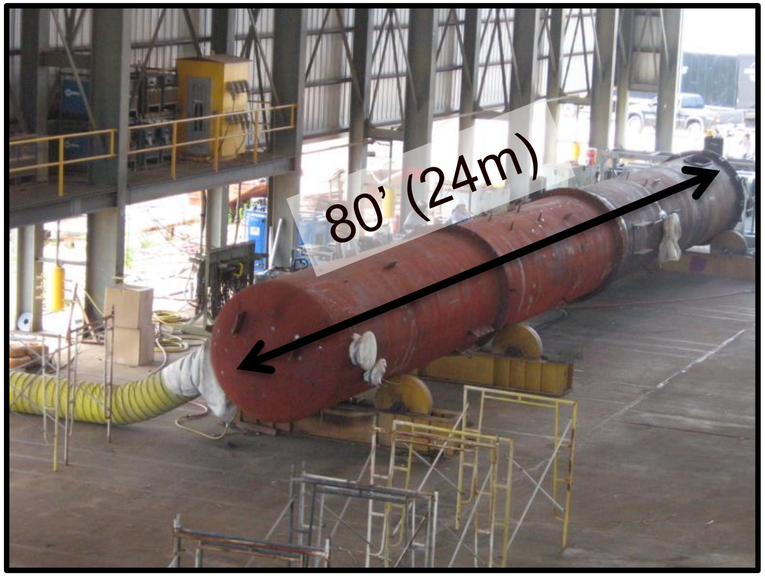


7/24	Continuous Run Time
	Modern alloy design consider: 14+ possible elements
!	20M+ possible alloys
	Requires RAD

Product Development Speed



Metco 8453 – Corrosion Resistant Coating for High Temperature Refinery Applications



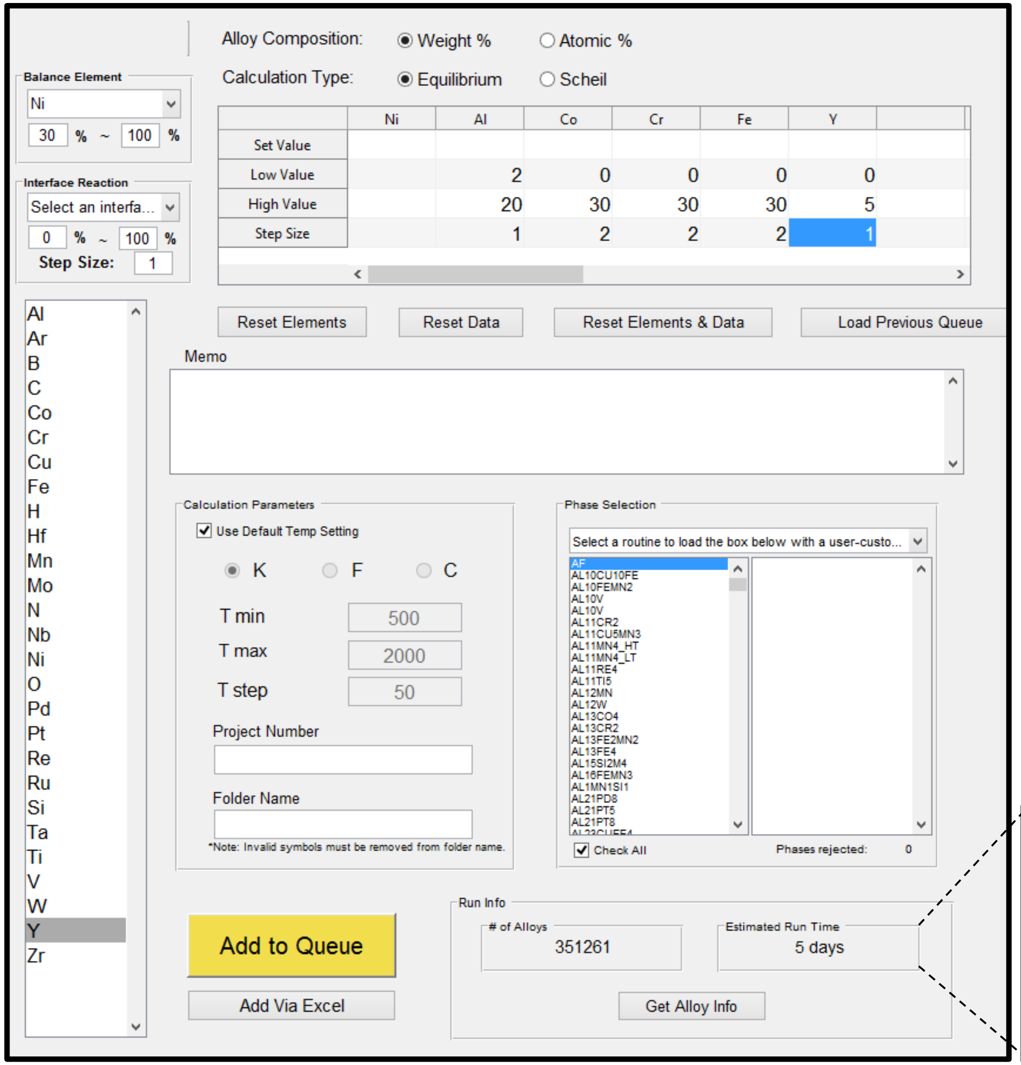
H_2S absorber

Steam Generator Hoods

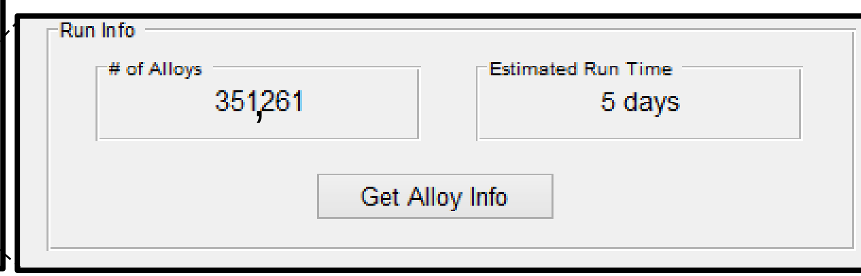
Metco 8453 is a Ni-based superalloy metallic coating developed with the RAD software in partnership with Chevron used successfully to protect a variety of refinery equipment from high temperature corrosion

BIG DATA Generation with RAD

oerlikon metco

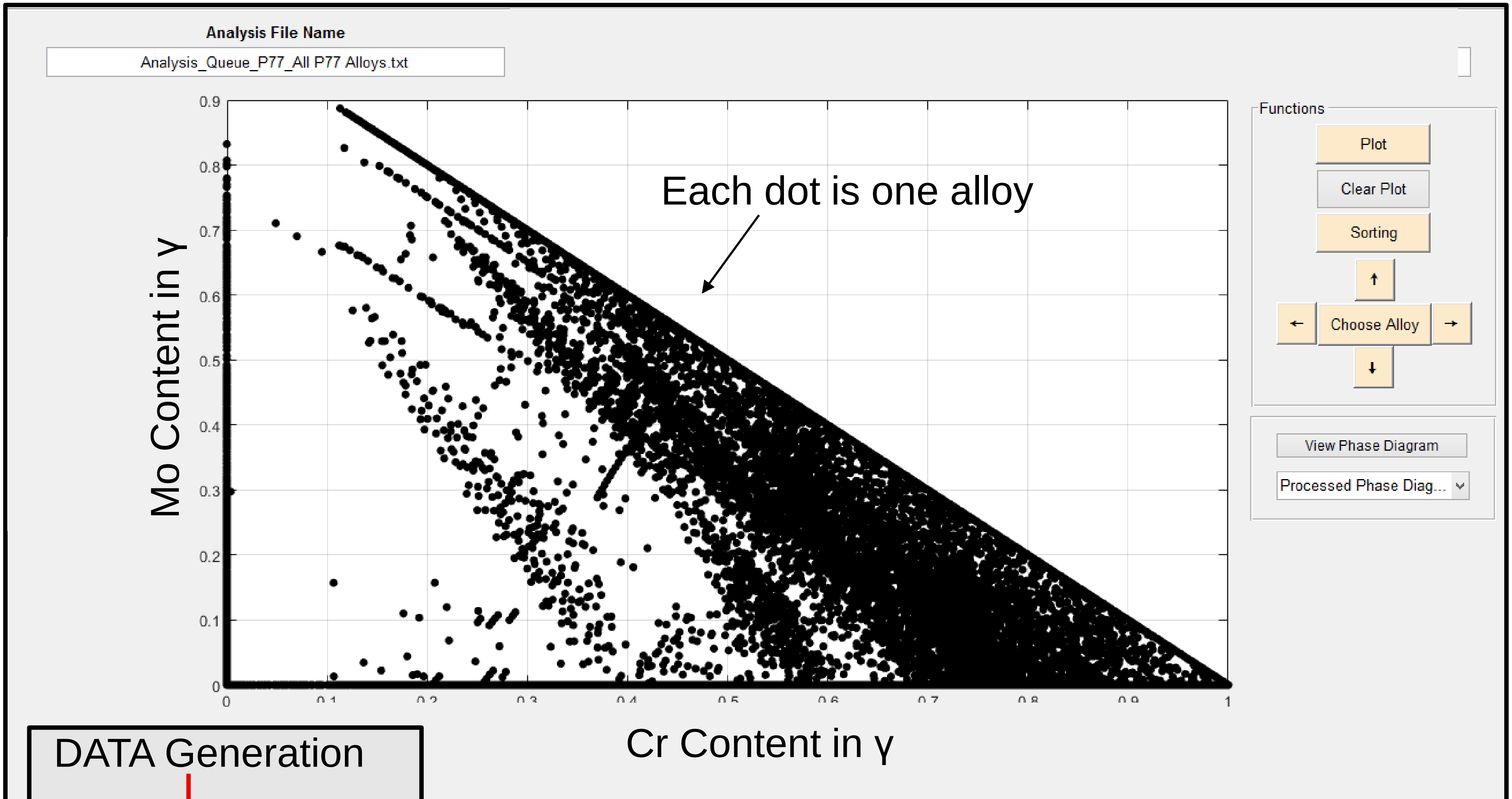


- ~7 Million Alloys and Ceramics Calculated Annually
- Designing Alloys (Fe, Ni, Al, Ti, Cu, Ag), Oxides, & Carbides
- Additive manufacturing, thermal spray, welding, laser cladding, brazing, and casting



The RAD software enables a materials scientist to explore vast compositional spaces and make intelligent design decisions quickly

BIG DATA Visualization with RAD



DATA Generation

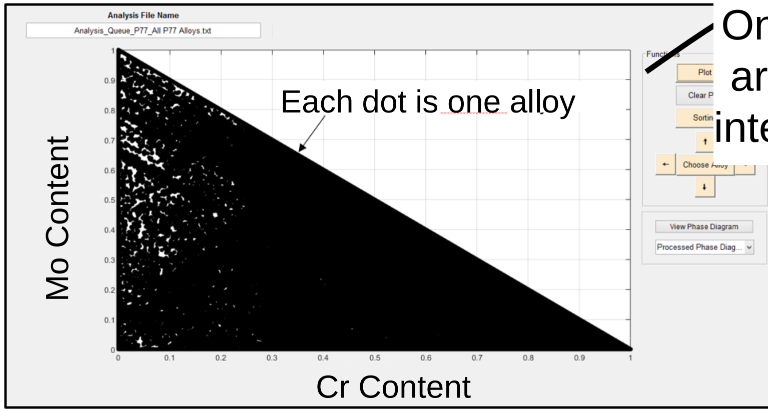
↓

DATA Mining

↓

DATA Visualization

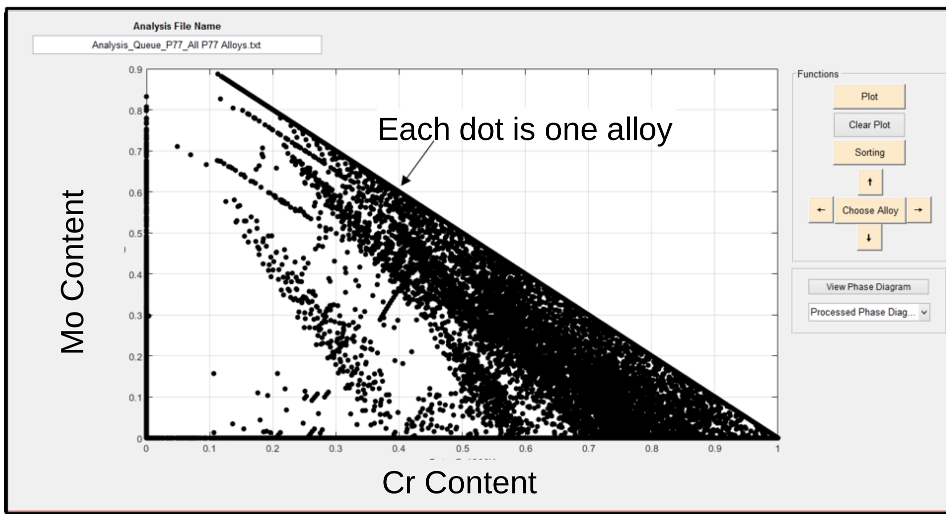
BIG DATA Visualization with RAD



1.3M Alloys in Chart

Only plot alloys with are not brittle (zero intermetallic phases)

275,000 Alloys in Chart



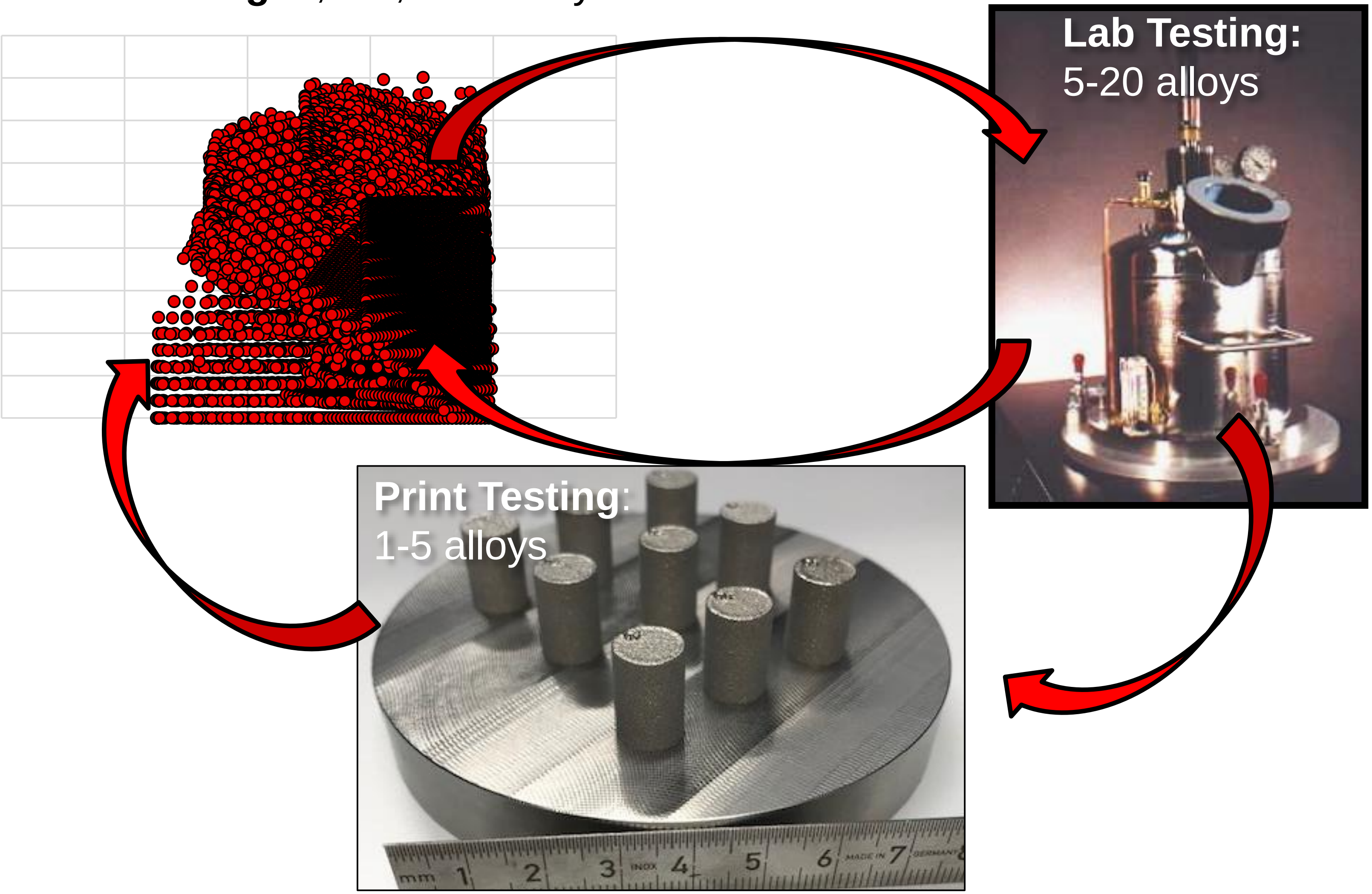
126,000 Alloys in Chart

Only plot alloys which can be printed crack free (certain solidification behavior)

Processing algorithms help sort through the data to identify several compositions of Interest

The RAD Design Process

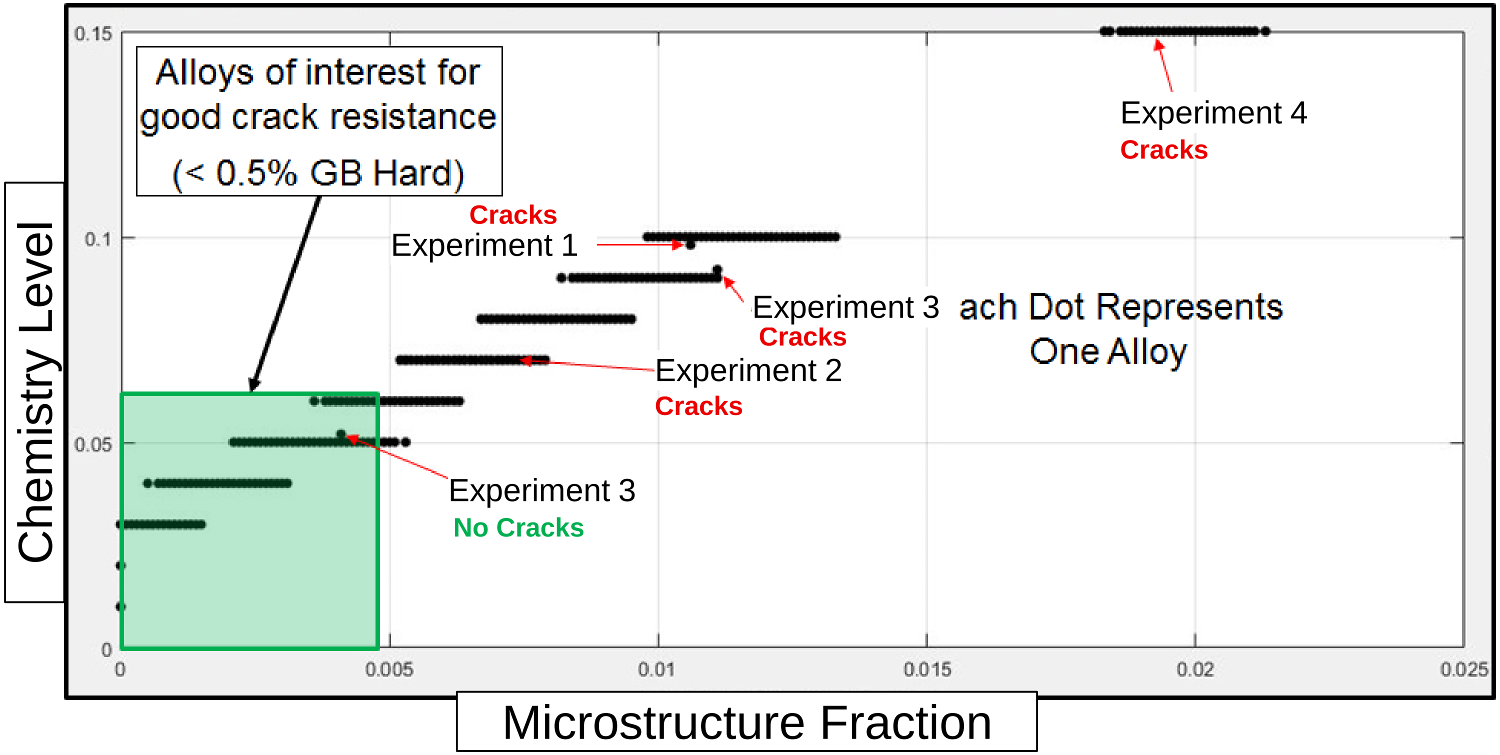
RAD Modeling: 1,300,000+ alloys



The ability to model and simultaneously evaluate many alloys enables Rapid Alloy Development

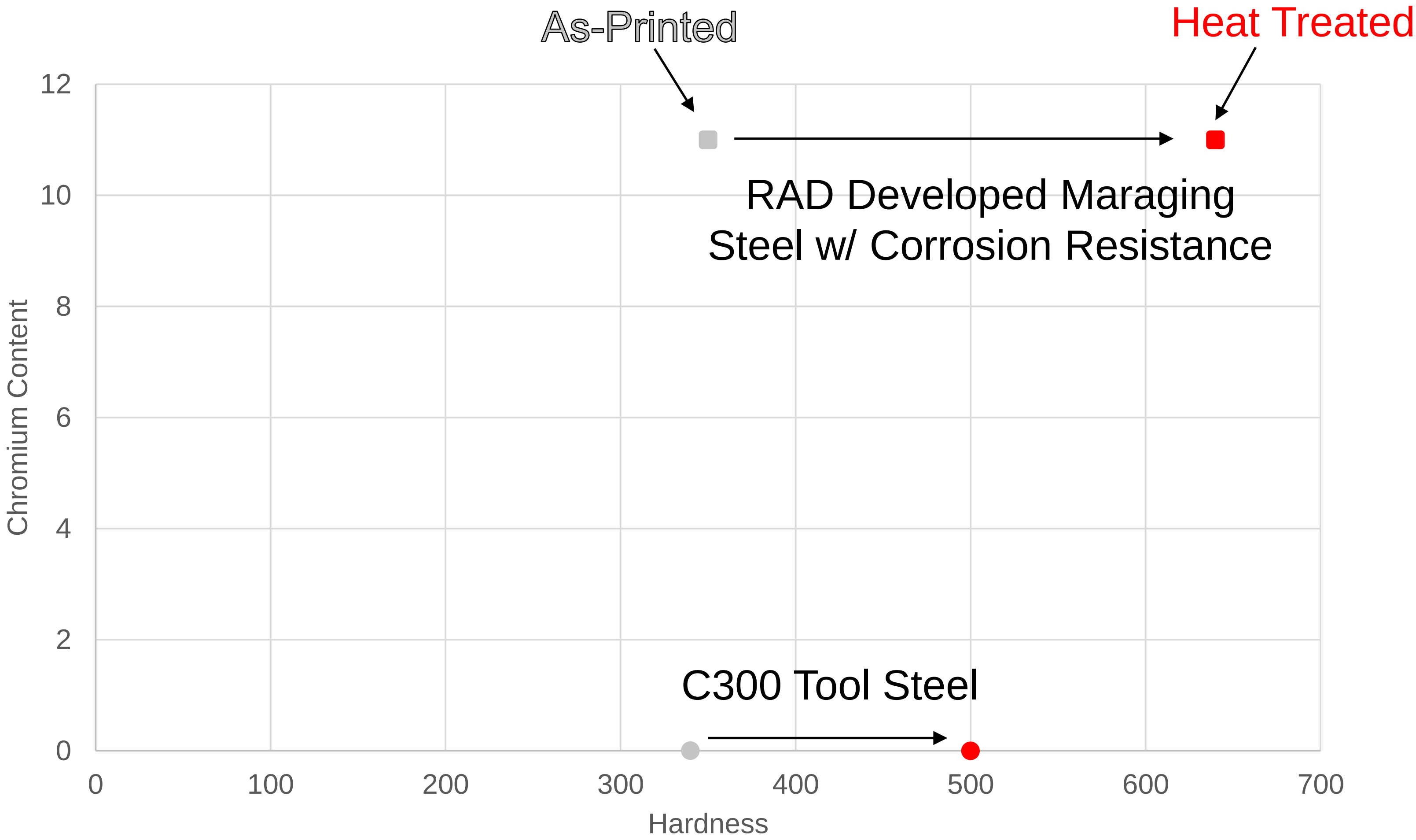
Modifying Existing Materials for AM

oerlikon metco



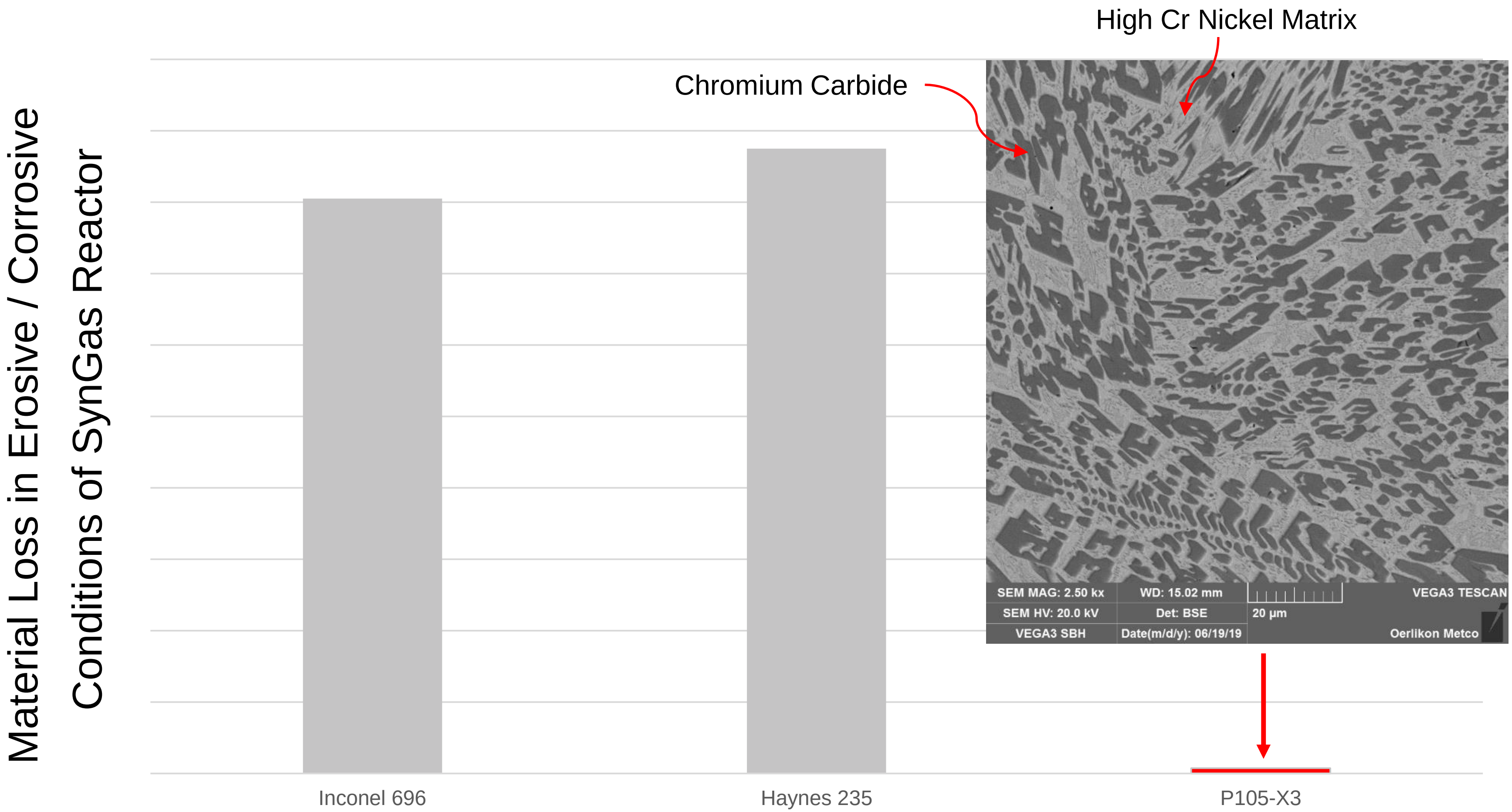
The RAD technology has assisted in determining the role of cracking in Haynes 230 and other superalloys when printed and how to adjust chemistry to avoid it.

Designing New Materials to Enhance Corrosion Resistance



Early results from an internal project to develop new maraging steels with enhanced corrosion resistance

Designing Alloys for Syngas Production



Protective coatings on heater tube bundles require resistance to high temperature erosion (from catalysts) and metal dusting due to the high carbon activity environment

RAD designed alloys (laser clad P105-X3) have great performance in both metal dusting & high temperature erosion

Appendix 12

Online Spray Visualization for Corrosion Prevention

(Roger Makhoul)

Online Spray Visualization for Corrosion Prevention

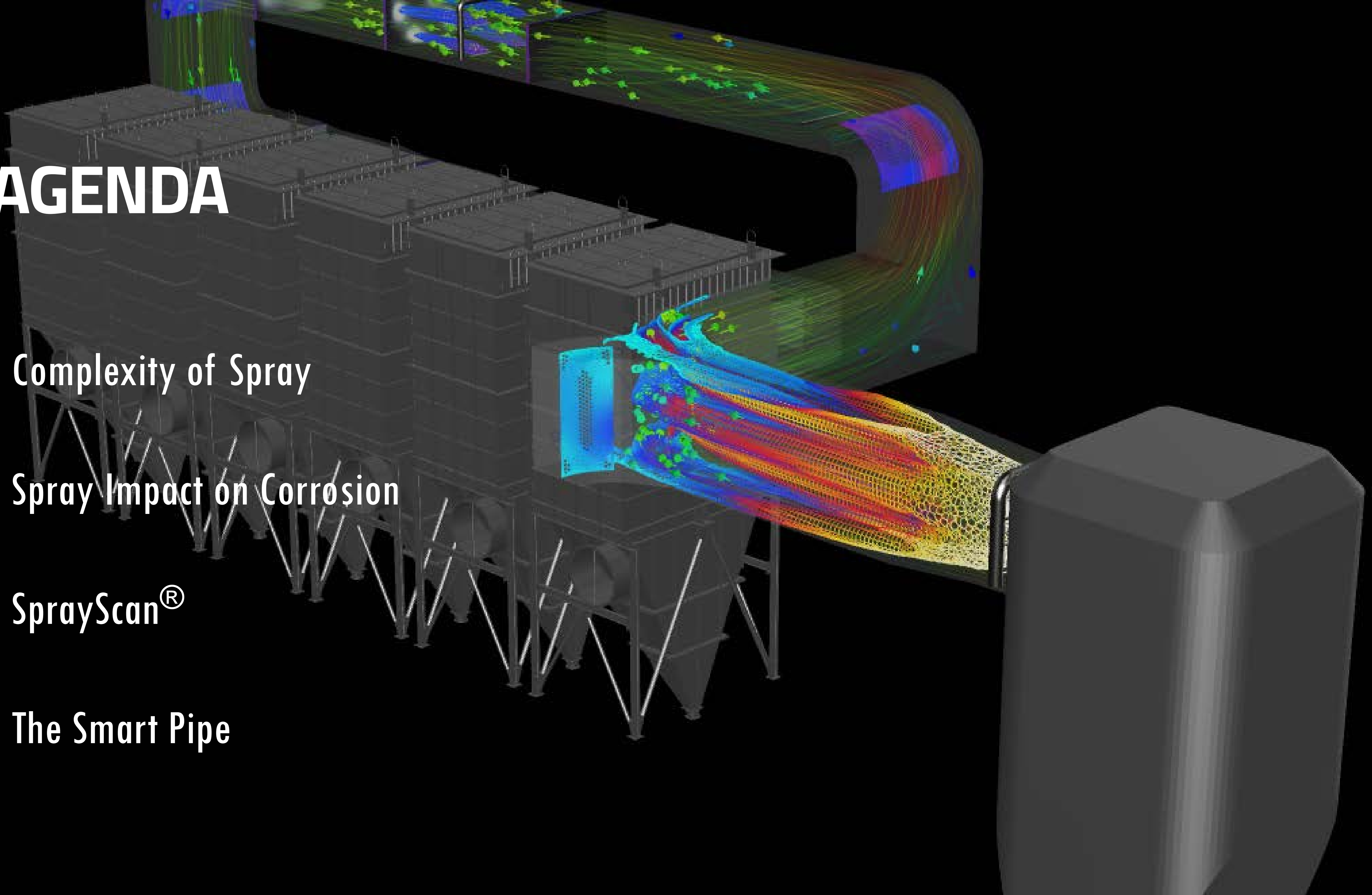
Roger Makhoul, Spraying Systems Co.

EFC WP15 Meeting

September 23, 2021

Spraying Systems Co.®
Experts in Spray Technology

AGENDA



Complexity of Spray

Spray Impact on Corrosion

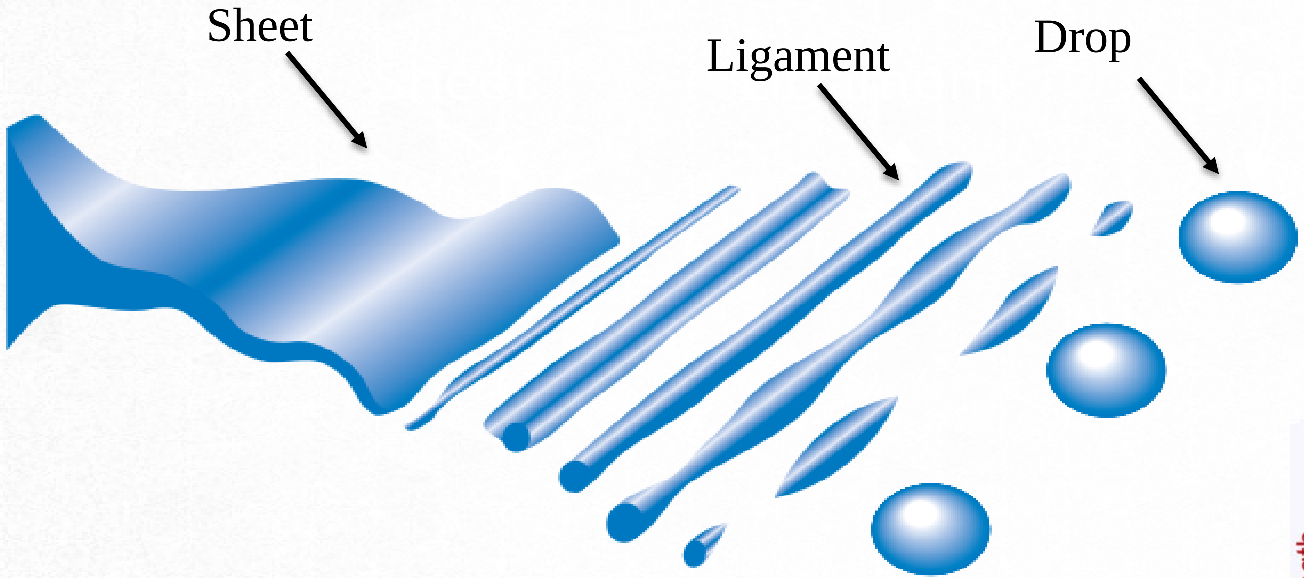
SprayScan®

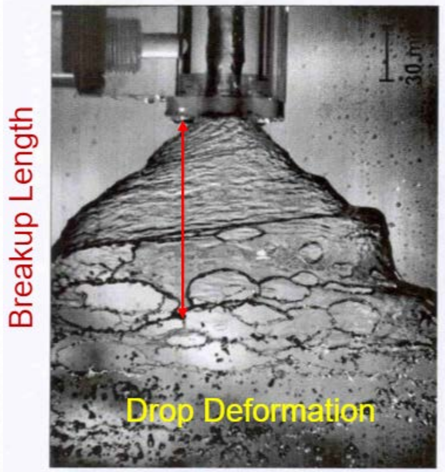
The Smart Pipe

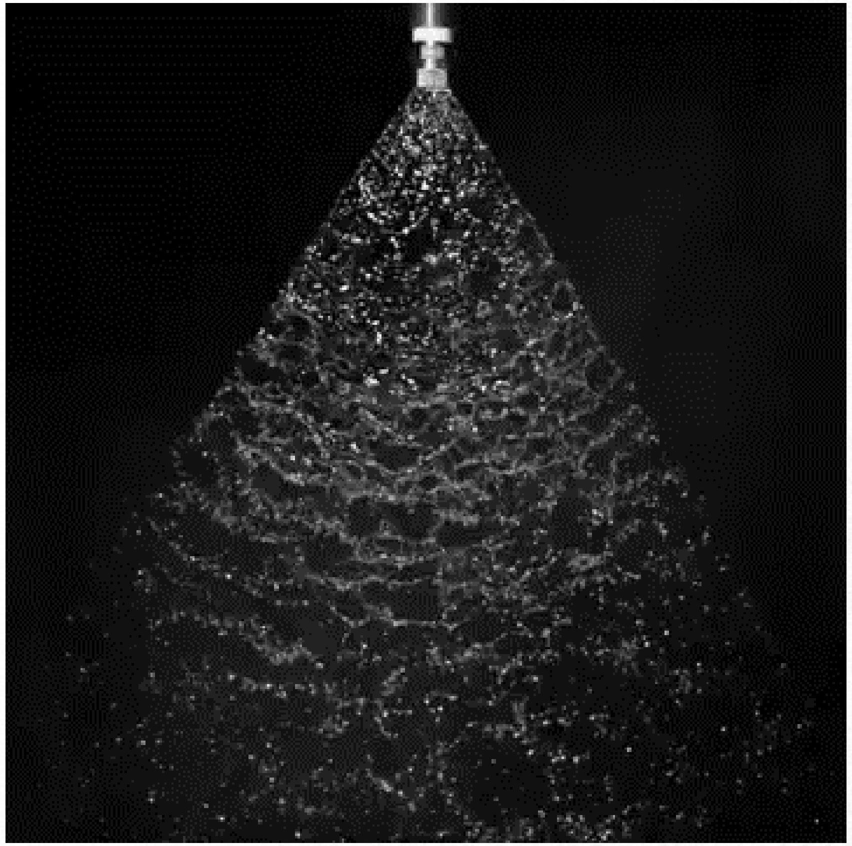
THE COMPLEXITY OF SPRAYS

Increasing Pressure

Primary Break-up

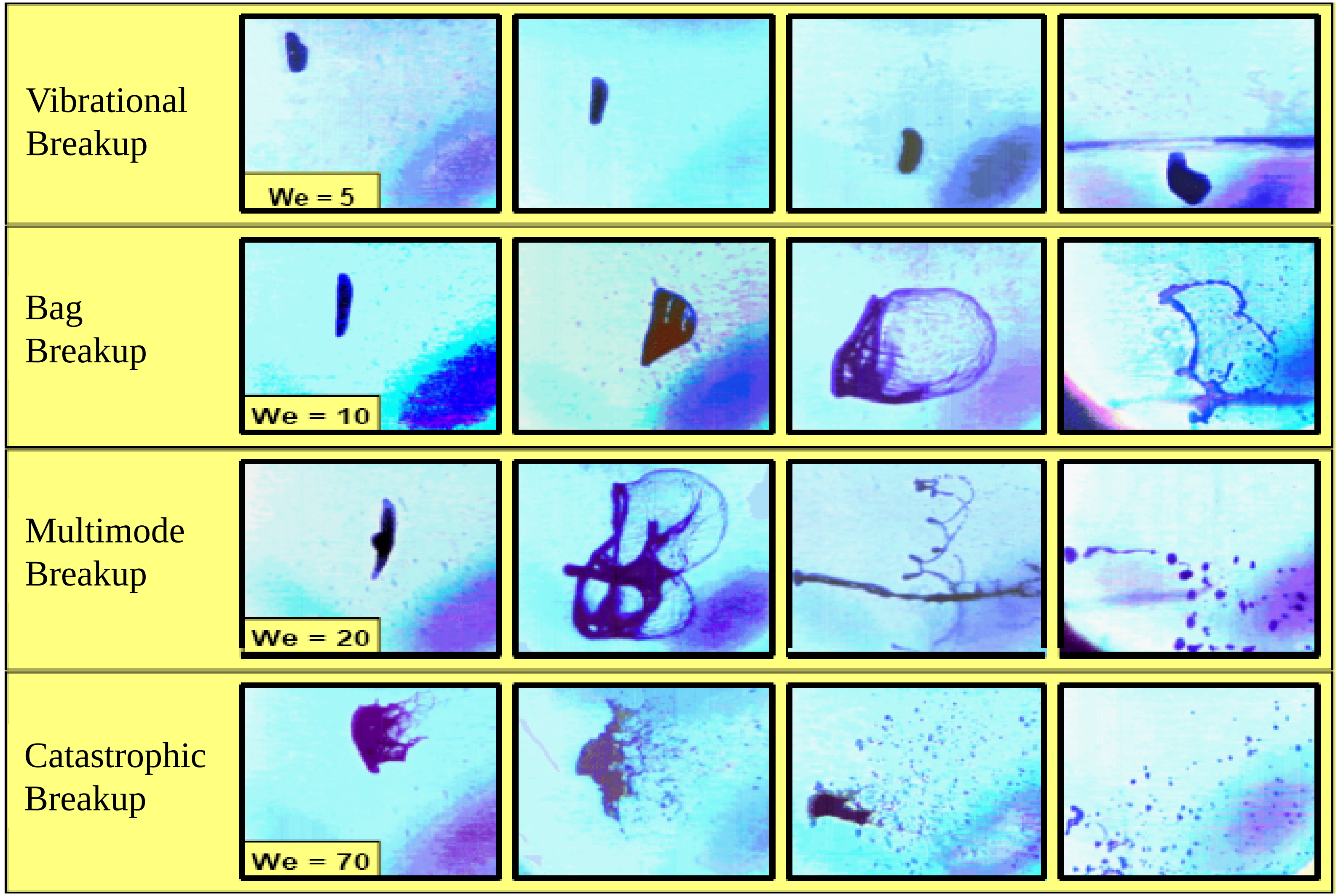




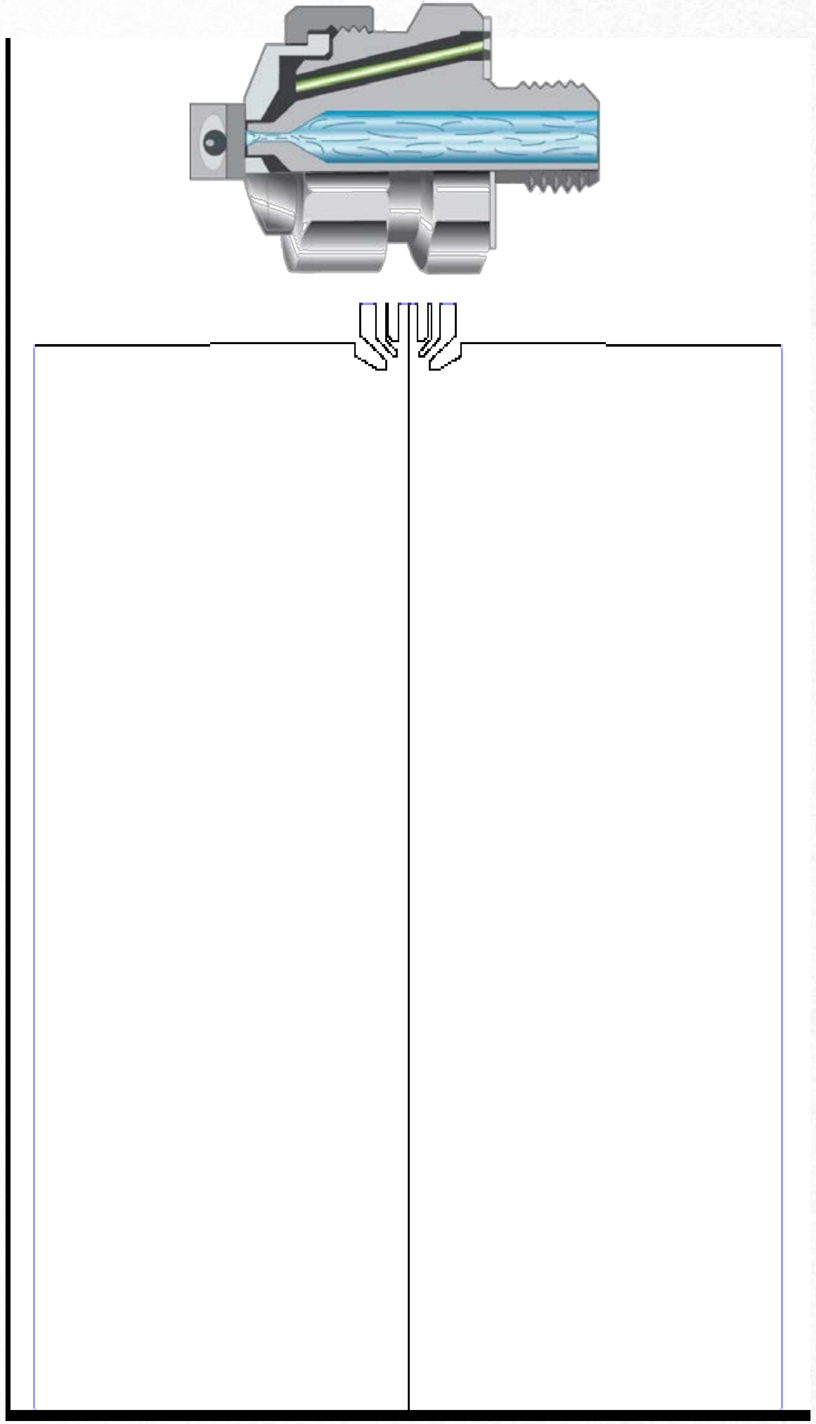


THE COMPLEXITY OF SPRAYS

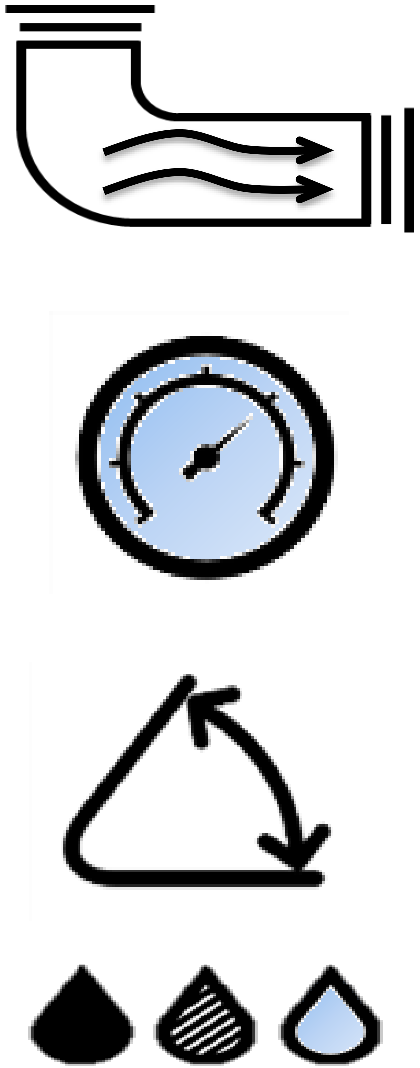
Secondary Breakup
Dual Phase Atomization

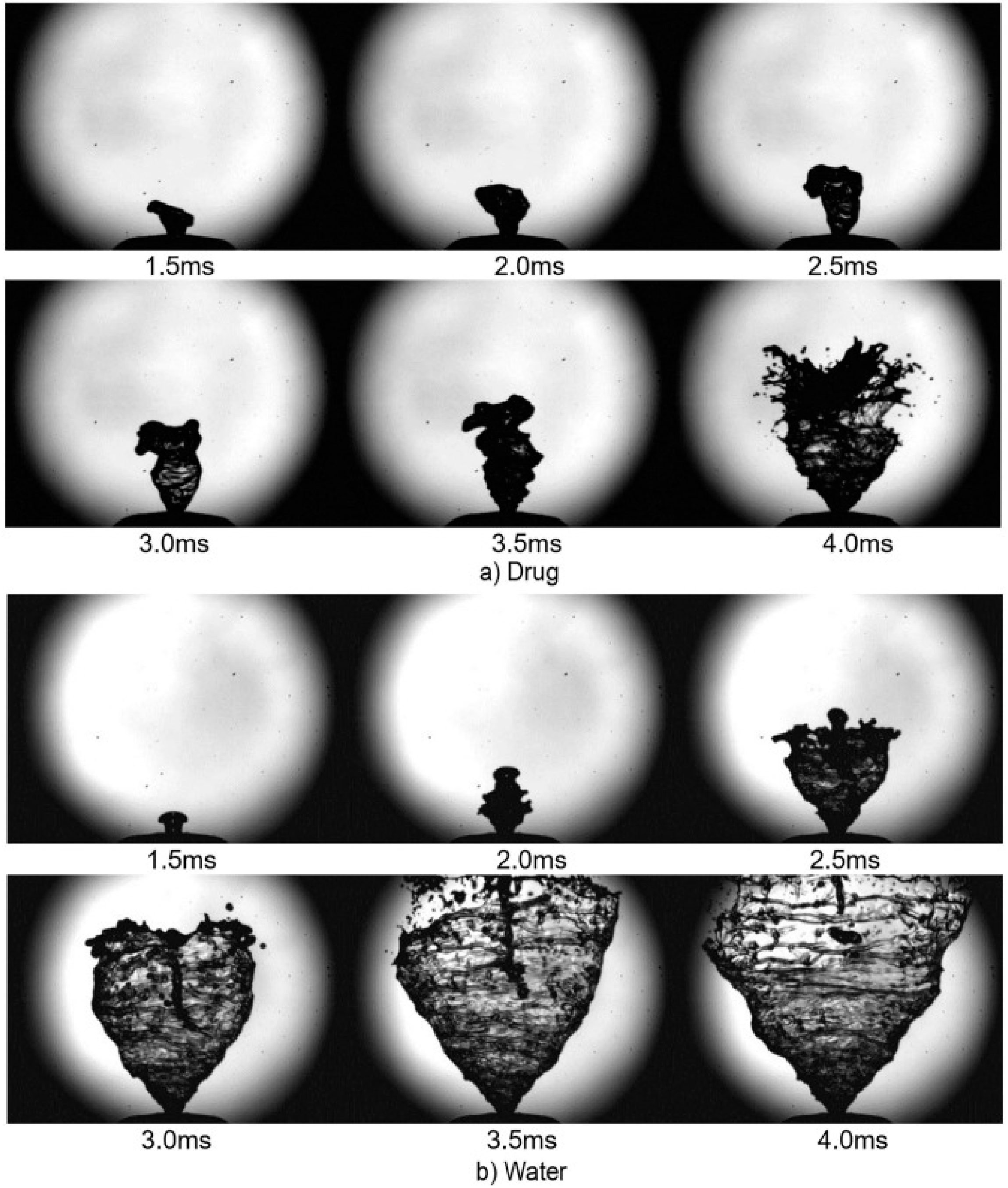


[9] Häßler, G.: Investigation of the destruction of water droplets by aerodynamic forces. Research in Engineering 38 (1972), pp. 183-192



MANY FACTORS AFFECT DROP SIZE





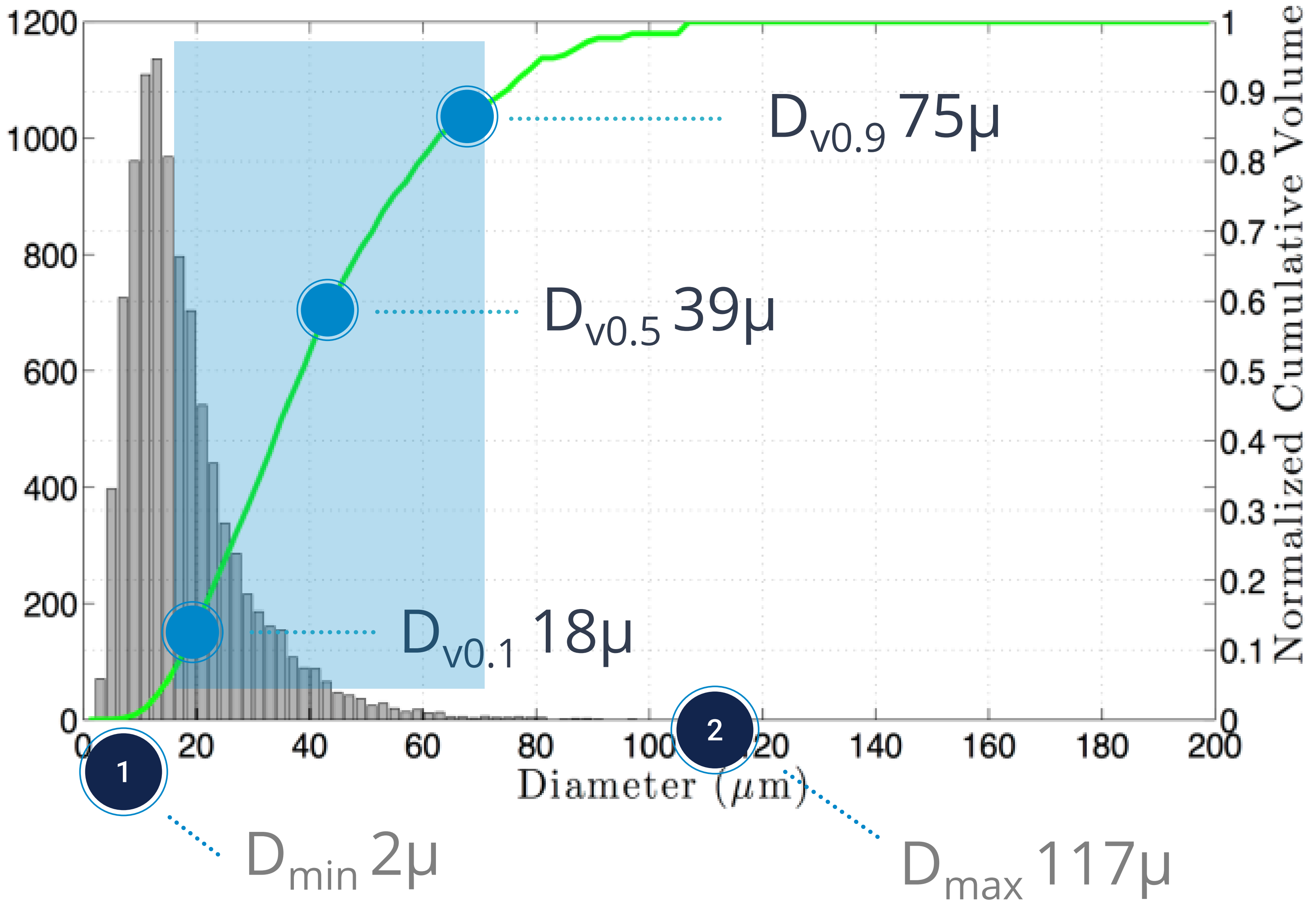
Drop Size Terminology: $D_{v0.1}$ $D_{v0.5}$ $D_{v0.9}$ D_{min} D_{max}

Volume Based

Best used for
spray material deposition
(i.e. coating, cooling, etc.)

Expressed as:

Rosin-Rammler
Diameter Distribution



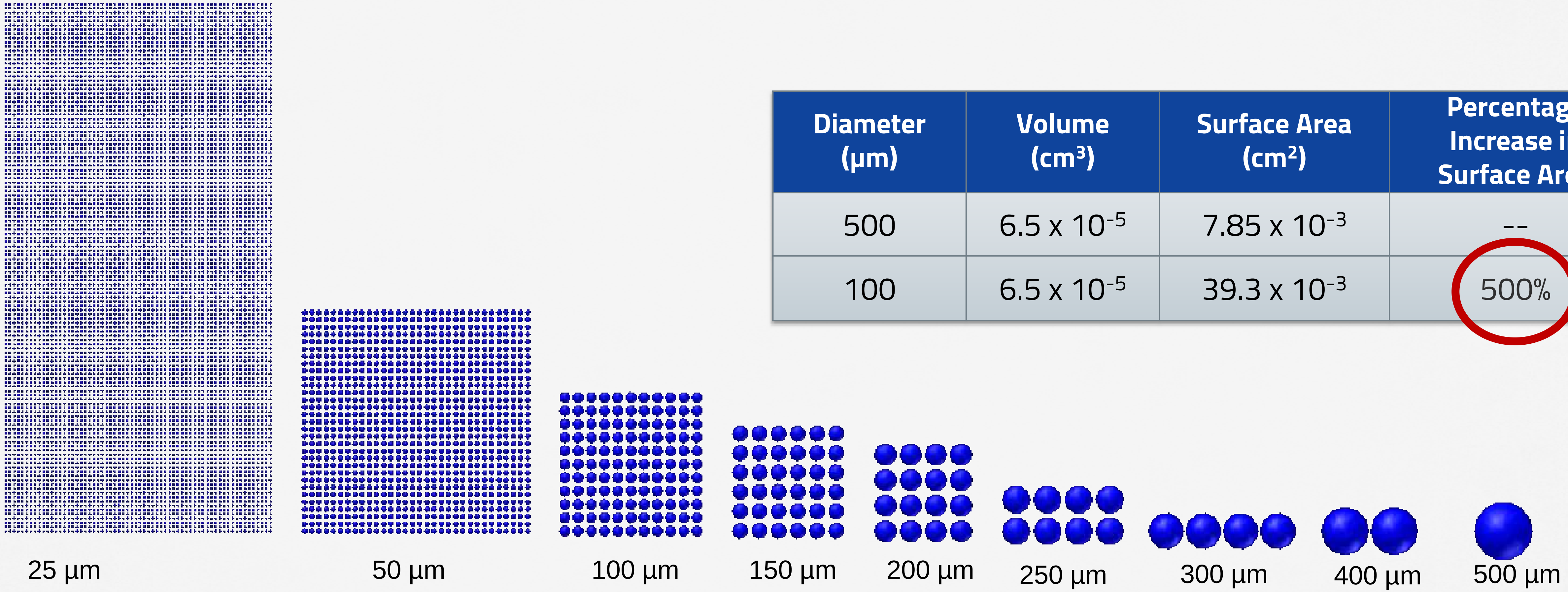
$$F(D) = 1 - e^{-\left(\frac{D}{\overline{\overline{X}}}\right)^{N}}$$

Drop Size Volume

Surface Area = $4\pi r^2$

Volume = $4/3\ \pi r^3$

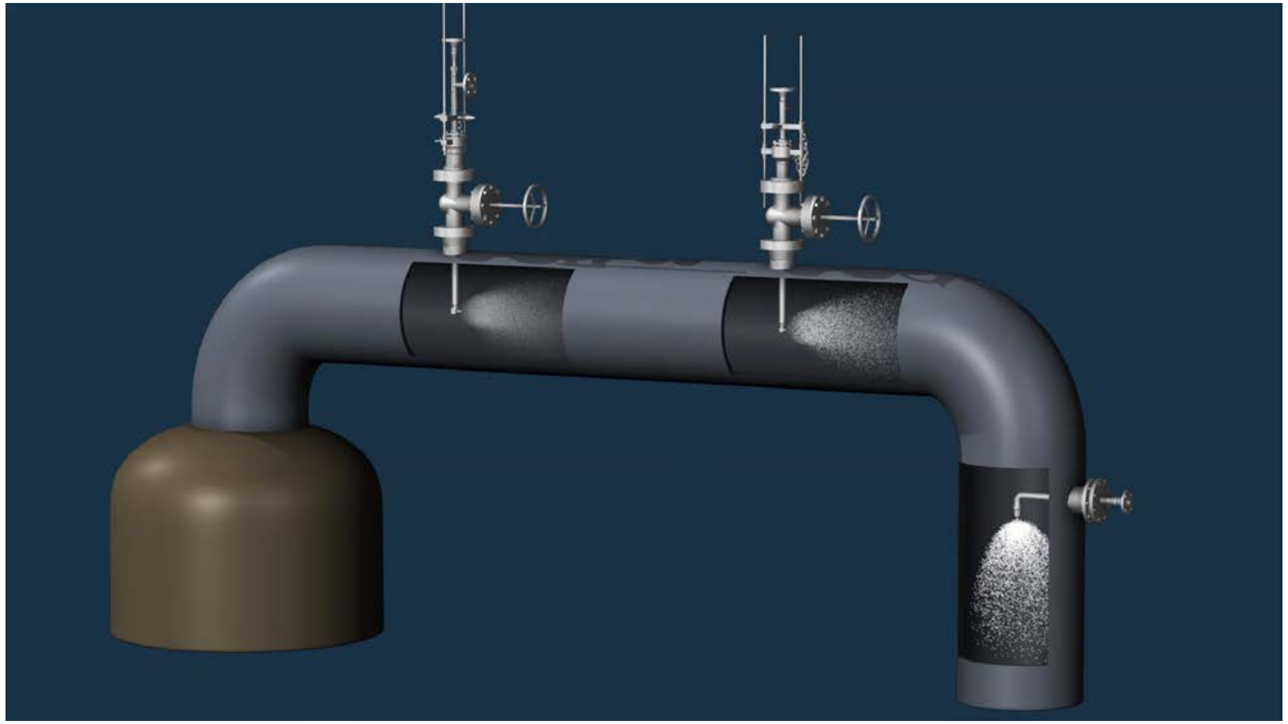
By volume, one 500µm droplet is equal to:

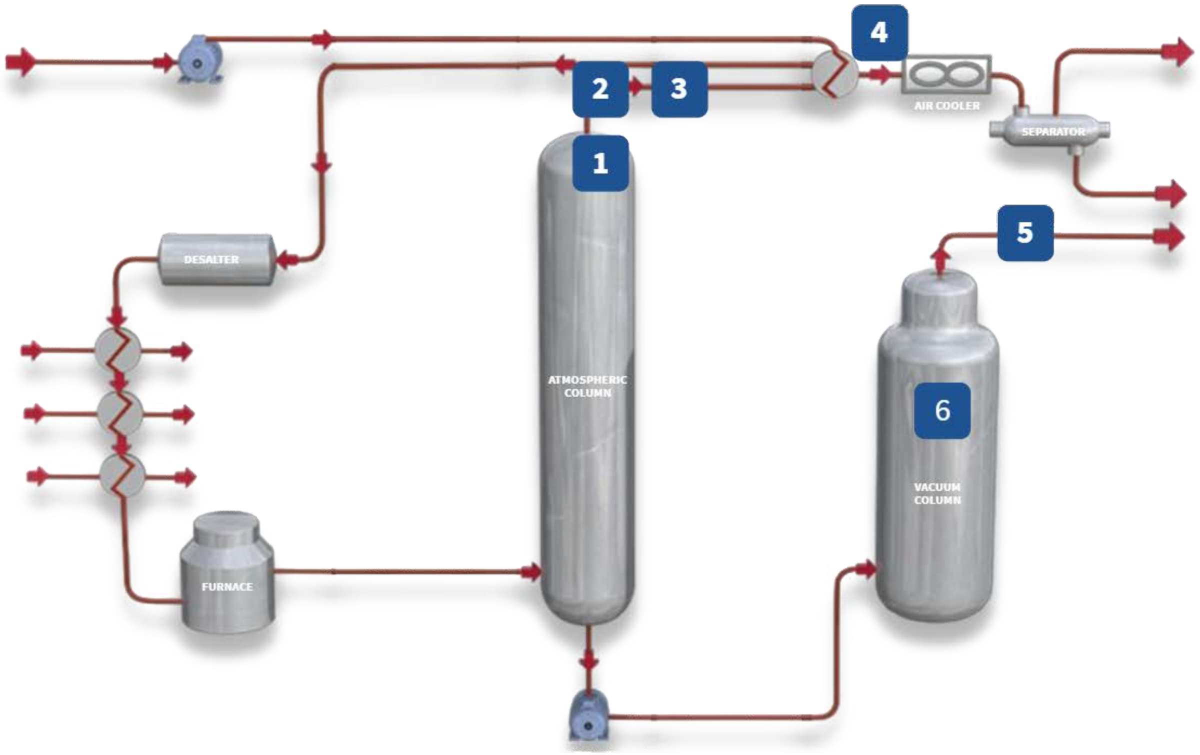


Diameter (µm)	Volume (cm^3)	Surface Area (cm^2)	Percentage Increase in Surface Area
500	6.5×10^{-5}	7.85×10^{-3}	--
100	6.5×10^{-5}	39.3×10^{-3}	500%

Note: Mass transfer is proportional to the surface area

Spray Performance Impact on Corrosion





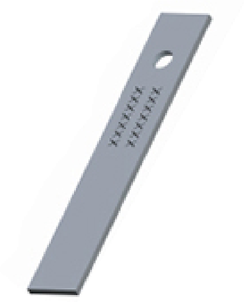
CDU Overhead

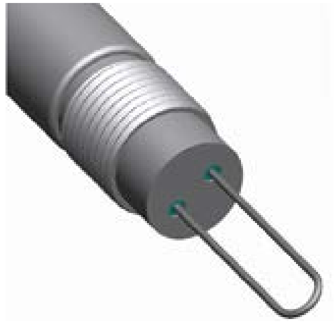
Corrosion Monitoring Technique

Reaction

Coupons

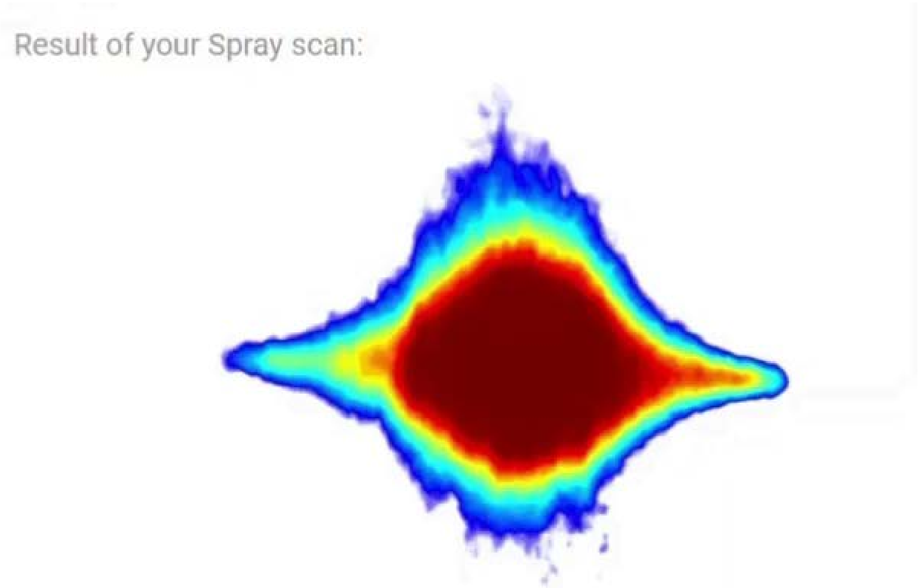
Probes

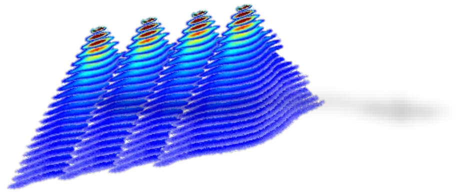




Prevention

SprayScan® Suite



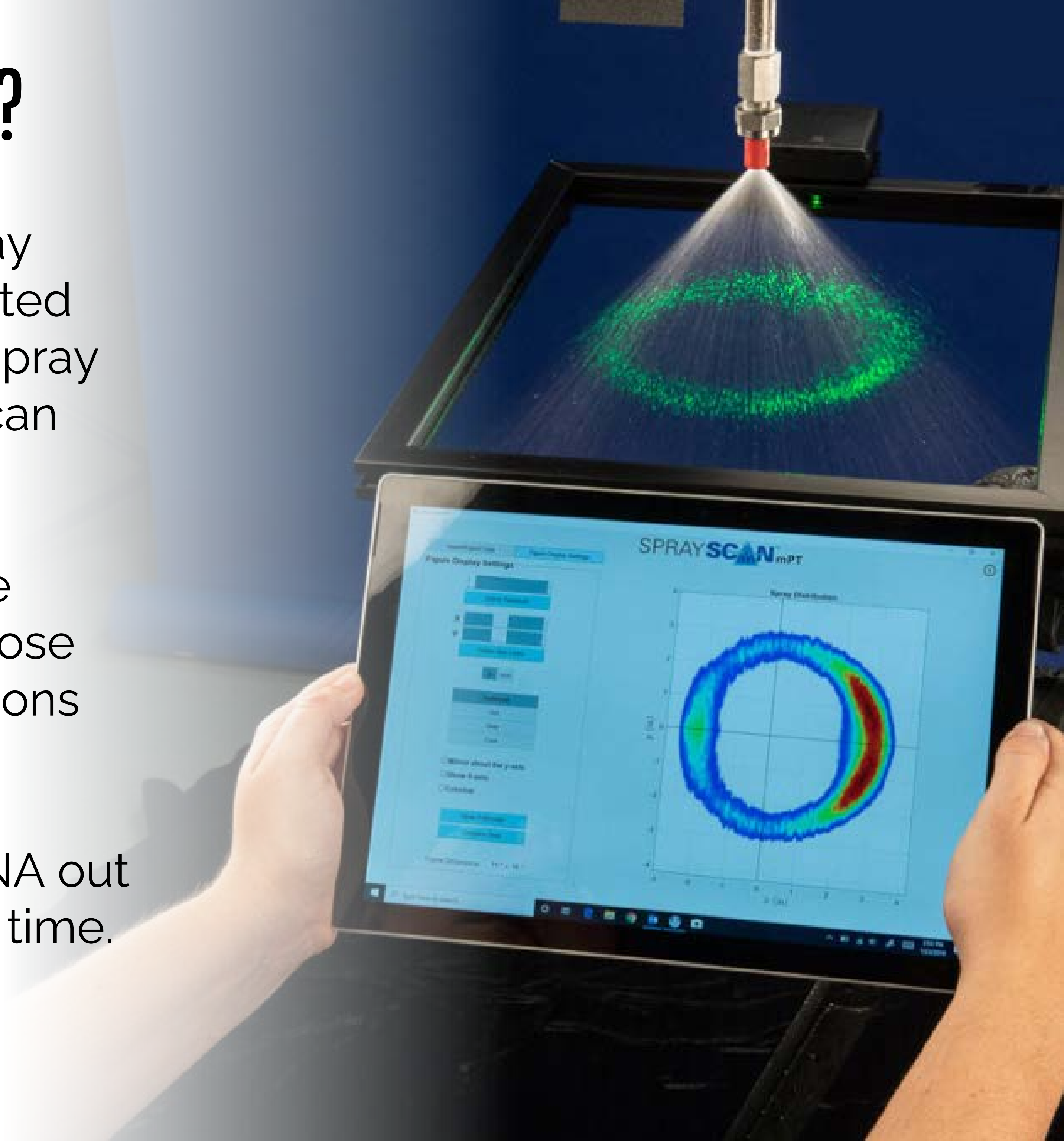


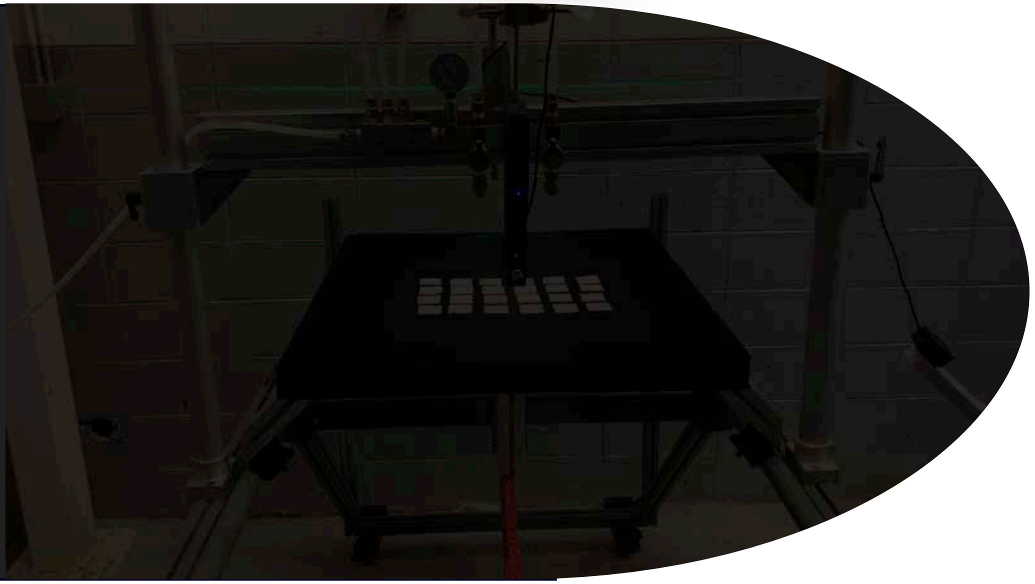
What is SprayScan® Suite?

We have taken our knowledge of spray testing and data collection and recreated simpler versions of bulky, expensive Spray Diagnostic Tools that almost anyone can run.

At much more affordable prices, these compact tools allow the user to diagnose potential issues in their spray applications within their own facility.

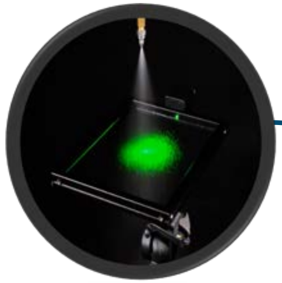
Bringing Spray Diagnostics, Nozzle DNA out of the Lab and into Your Hands in real time.





SprayScan Suite:
Online Assessment for Spray Quality to Prevent Corrosion

SPRAYSCAN™ mPT



Evaluates a spray pattern, by assessing dispersed droplets.

SPRAYSCAN™ mSM

Displays your spray system's flow rate, pressure, and temperature in real-time

SPRAYSCAN™ mDS

Analyze your drop size data

Spraying Systems Co.®

SPRAYSCAN™ mPT

mobile Patternator

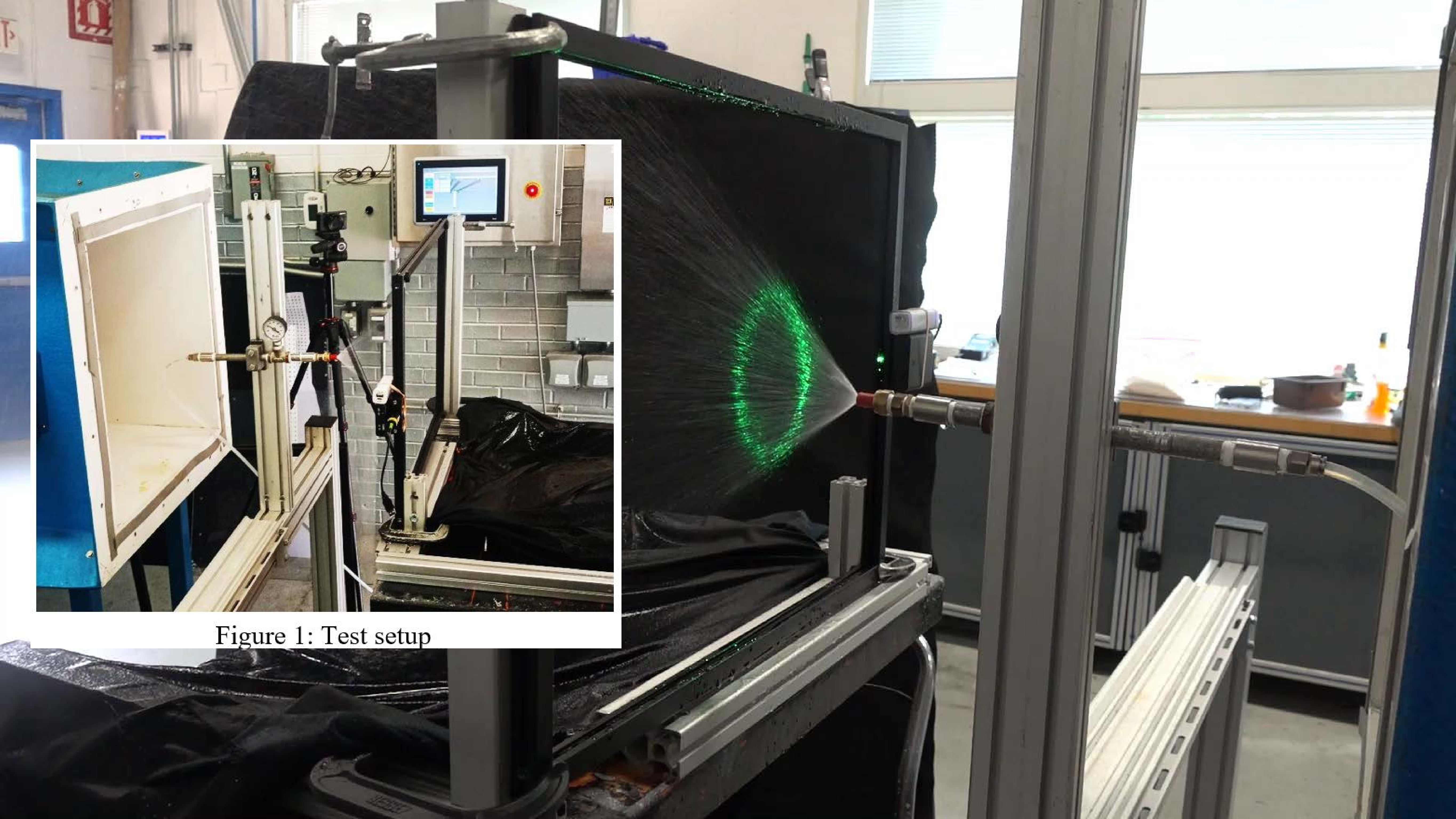
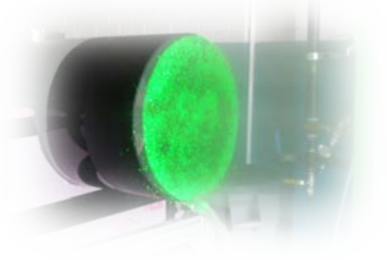


Figure 1: Test setup



Validating Performance

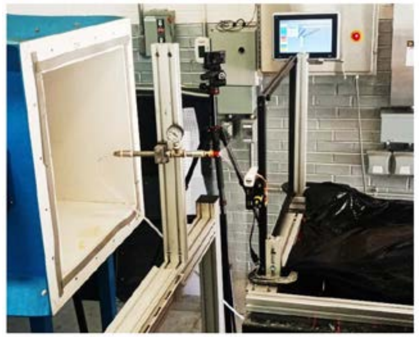
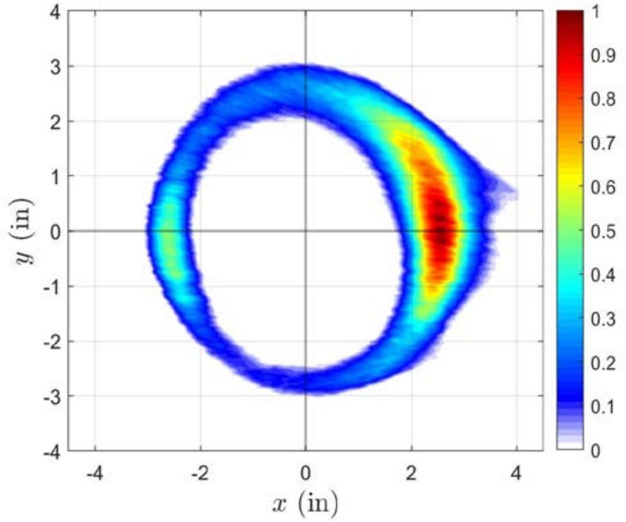
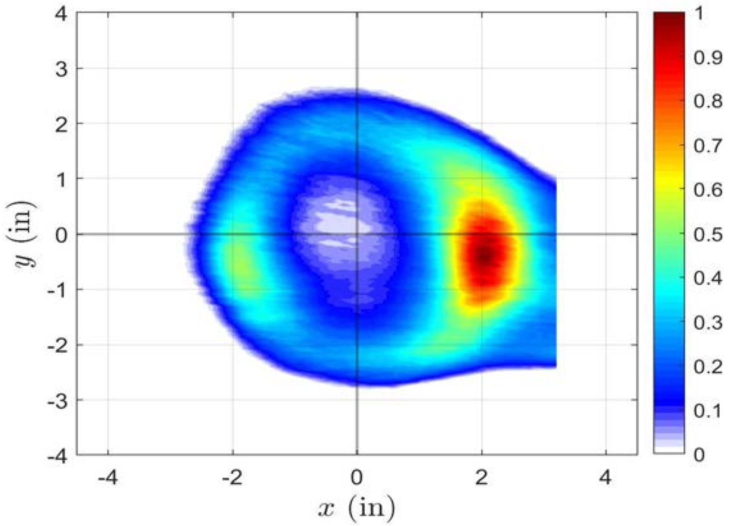


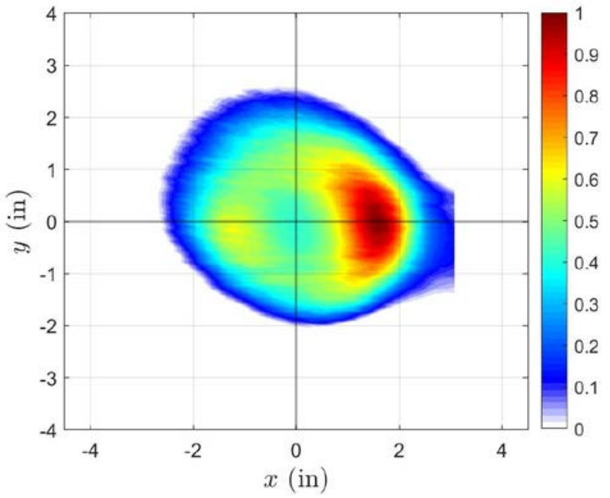
Figure 1: Test setup



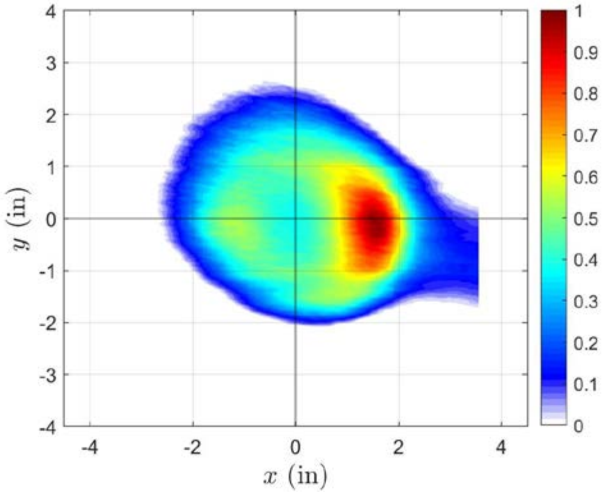
0 m/s



15 m/s



25 m/s



30 m/s

Wind Velocity	Area (in^2)	Coverage Reduction
0 m/s	30.1	0%
15 m/s	25.8	14%
25 m/s	19.2	36%
30 m/s	18.4	39%

SPRAYSCAN™ mSM

Measure your spray system's flow rate, pressure, and temperature in real-time.

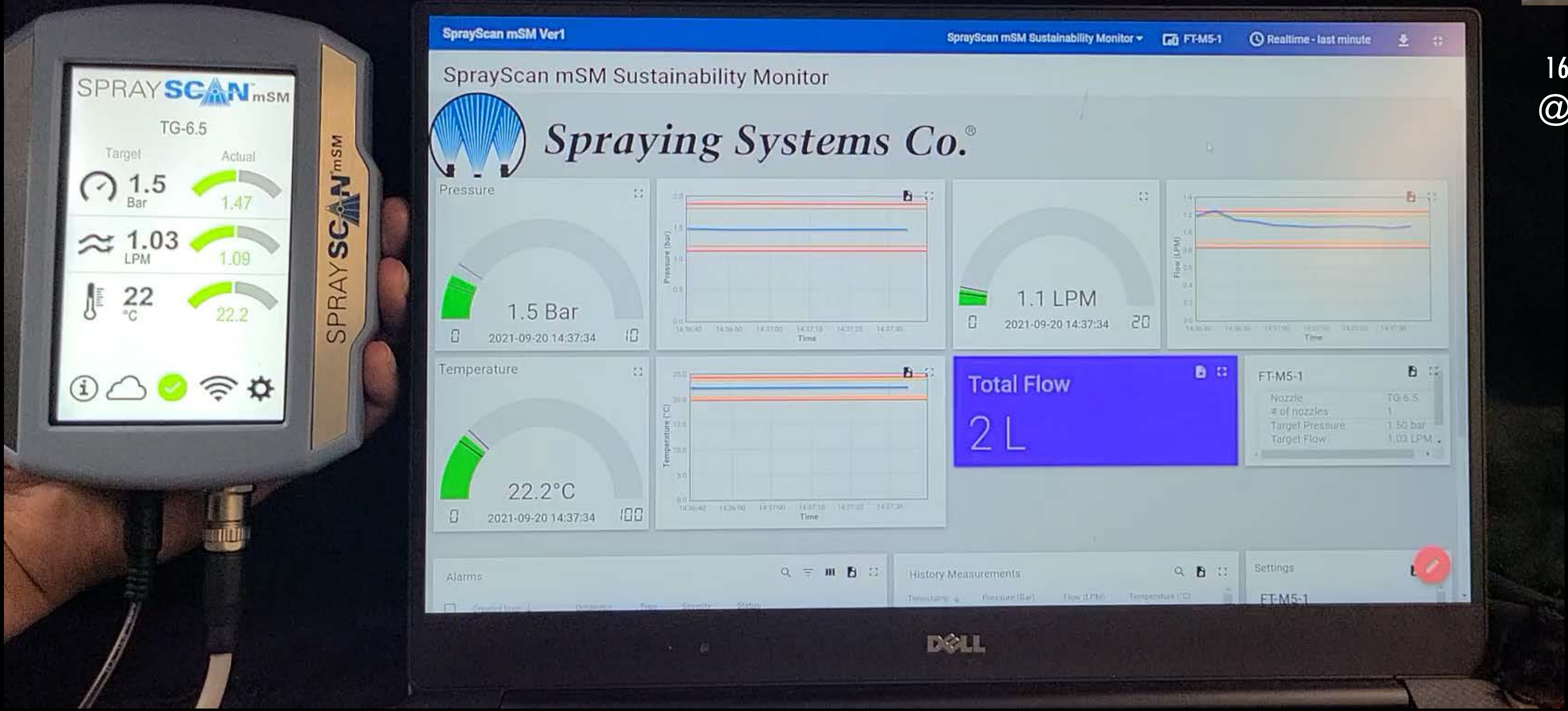
Online dashboard to monitor the Sustainability Monitor and the spray process being monitored.

Wi-Fi connectivity to online dashboard server. Ethernet connectivity in development.

View real-time and historical data.

Alarms within the dashboard and optional SMS and email alarms when the spray process is operating outside of accepted ranges.

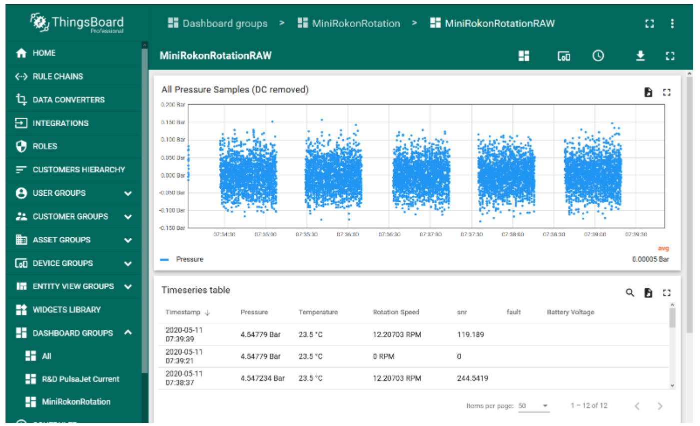
SPRAYSCAN™ mSM

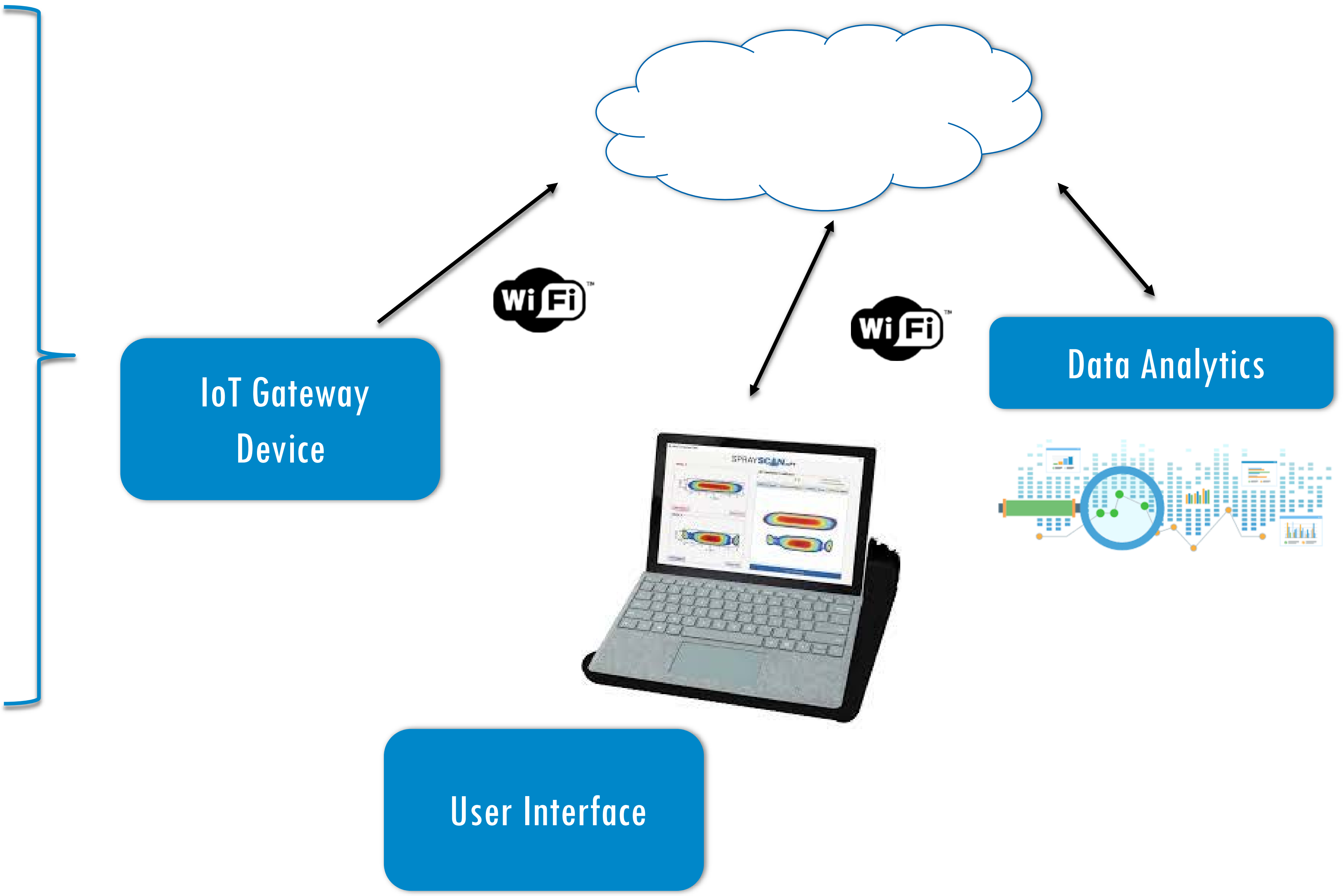


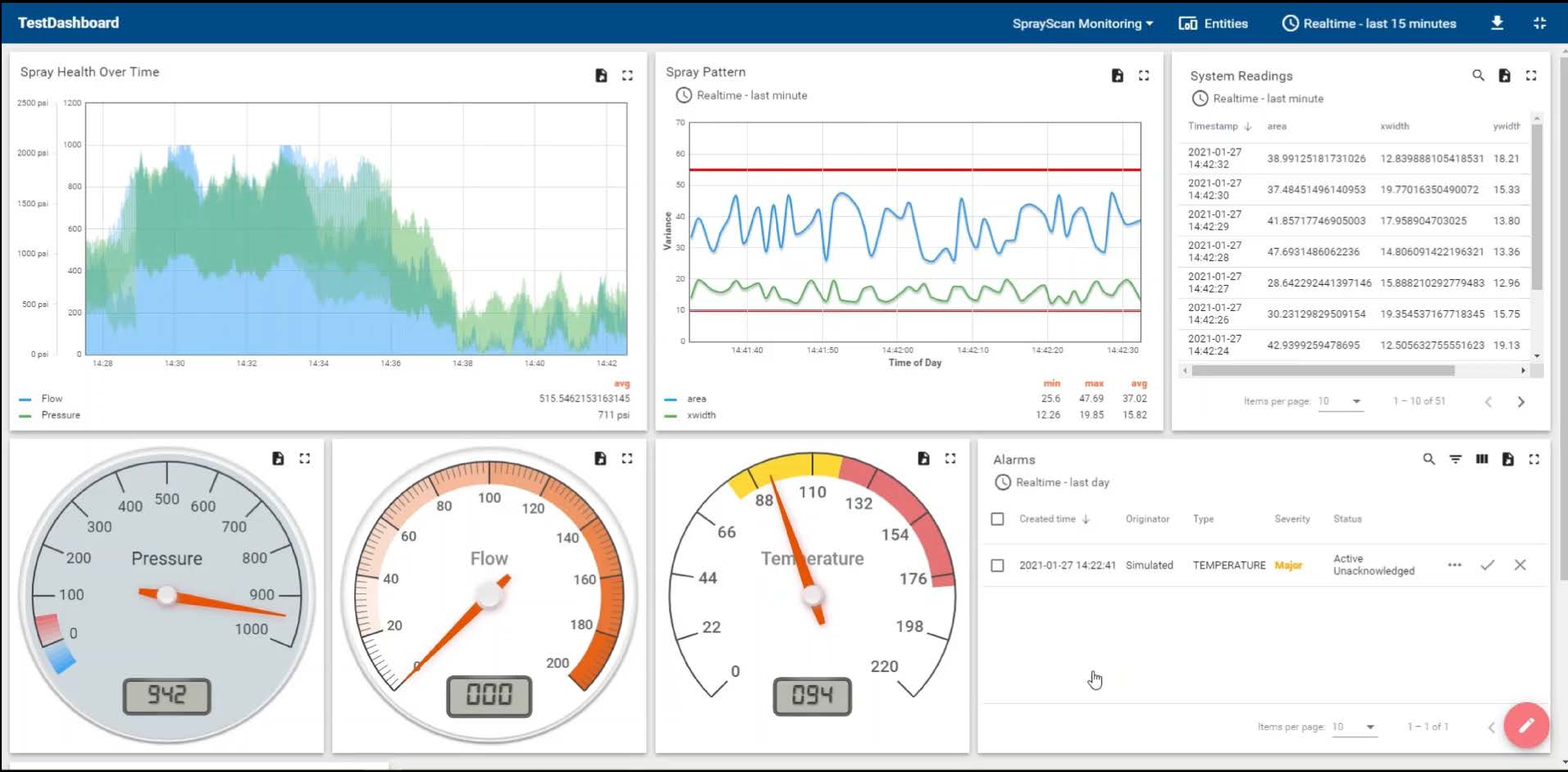
163 LPM
@3 BARG

87 LPM
@ 3 BARG

The Smart Pipe






TestDashboard
SprayScan Monitoring
Entities
Realtime - last 15 minutes
Spray Health Over Time
2500 psi
2000 psi
1500 psi
1000 psi
500 psi
0 psi
1200
1000
800
600
400
200
0
14:28
14:30
14:32
14:34
14:36
14:38
14:40
14:42
avg
Flow 515.5462153163145
Pressure 711 psi
Spray Pattern
Realtime - last minute
Variance
Time of Day
14:41:40
14:41:50
14:42:00
14:42:10
14:42:20
14:42:30
min max avg
area 25.6 47.69 37.02
xwidth 12.26 19.85 15.82
System Readings
Realtime - last minute
Timestamp area xwidth ywidth
2021-01-27 14:42:32 38.99125181731026 12.839888105418531 18.21
2021-01-27 14:42:30 37.48451496140953 19.77016350490072 15.33
2021-01-27 14:42:29 41.85717746905003 17.958904703025 13.80
2021-01-27 14:42:28 47.6931486062236 14.806091422196321 13.36
2021-01-27 14:42:27 28.642292441397146 15.888210292779483 12.96
2021-01-27 14:42:26 30.23129829509154 19.354537167718345 15.75
2021-01-27 14:42:24 42.9399259478695 12.505632755551623 19.13
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1 – 10 of 51
Pressure
942
Flow
000
Temperature
094
Alarms
Realtime - last day
Created time Originator Type Severity Status
2021-01-27 14:22:41 Simulated TEMPERATURE Major Active Unacknowledged
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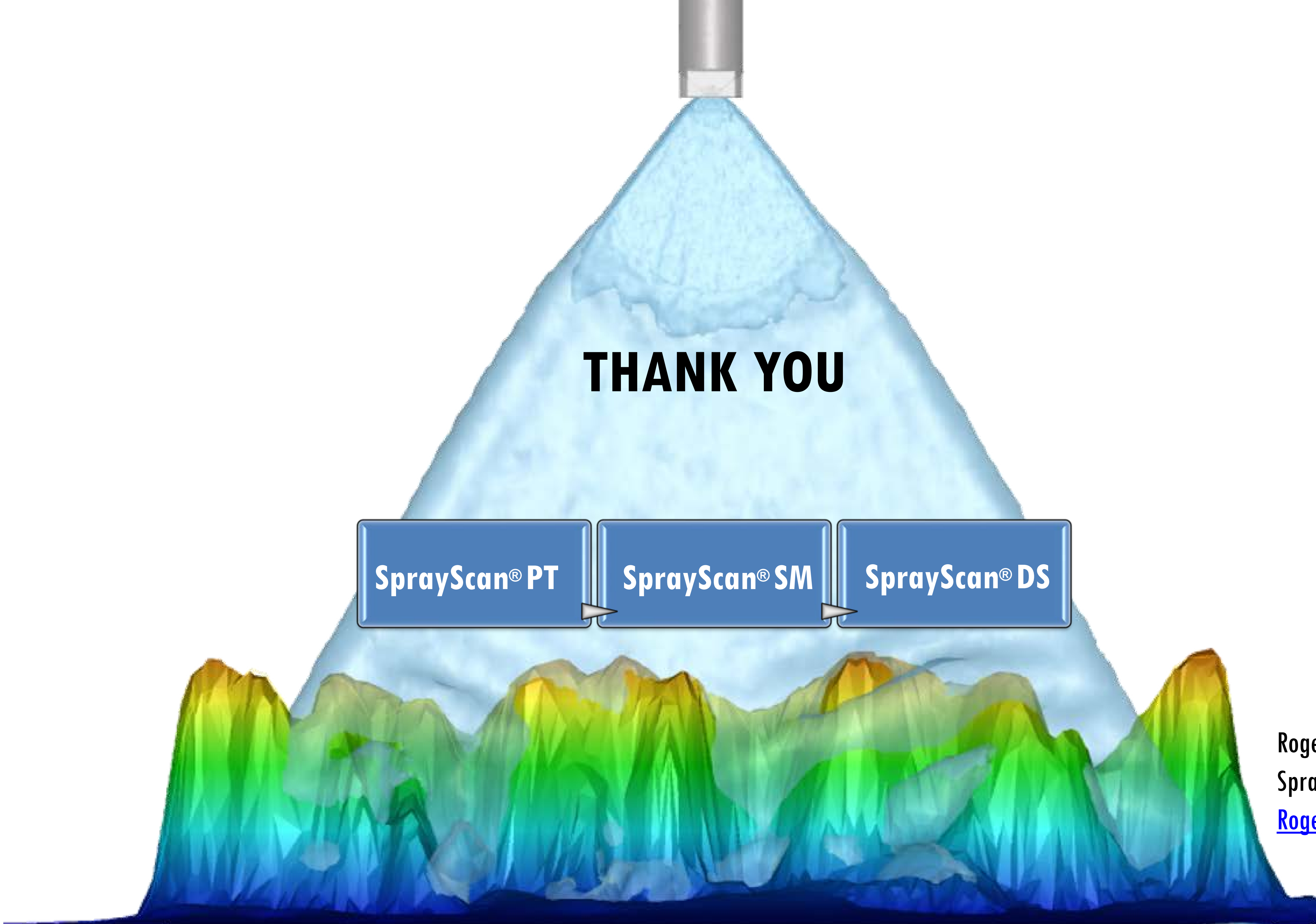
1 – 1 of 1

THANK YOU



Roger Makhoul
Spraying Systems Co.
Roger.Makhoul@spray.com

Appendix 13

Prediction of high temperature sulfidation and naphthenic acid corrosion in transfer lines and furnace' tubes – model development

(Slawomir Kus)





PREDICTION OF HIGH TEMPERATURE SULFIDATION AND NAPHTHENIC ACID CORROSION IN TRANSFER LINES AND FURNACE' TUBES – MODEL DEVELOPMENT

Honeywell

EFC WP15 MEETING, BUDAPEST 2021

SUMMARY

Excerpt:

Presentation deals with progress in development of Crude corrosivity model. Goals and tasks from Phase I and Phase II Joint Industry Research Programs (JIPs) by Honeywell, were presented. New features like calculation of H2S partial pressure from sulfur speciation and impact of high wall shear stress (WSS) parameters (up to 1000Pa) were also showed.

Presentation Plan

1. Crude corrosivity - recap
   1. Nap acid corrosion & sulfidation – key parameters
2. Crude corrosivity model development – Phase 1 recap
3. Crude corrosivity model development – Phase 2
   1. Tasks, goals and results
   2. New model and future work in Phase 3
4. Summary

Full presentation in pdf file is available on request.

Please contact: Dr Slawomir Kus (Slawomir.kus@honeywell.com)

Honeywell