Appendix 1

List of participants

ON SITE			
NAME	**SURNAME**	**COMPANY**	**COUNTRY**
Alsalem	Mustafa M.	Saudi Aramco	SAUDI ARABIA
Andari	Fouad	Total Energies	FRANCE
Bateman	Colin	Integrated Global Services	UK
Bosmans	Peter	Sitech	NETHERLANDS
Bour Beucler	Valerie	Nalco Water	FRANCE
Buchheim	Gerrit	Becht	USA
Casu	Carlo	Istituto Italiano della Saldatura	ITALY
Claesen	Chris J	Nalco Champion	BELGIUM
de Bruyn	Hennie	Becht	NORWAY
De Landtsheer	Gino	Borealis	BELGIUM
de Marco	Marco	Istituto Italiano della Saldatura	ITALY
Eide	Staale	Emerson	NORWAY
Ervik	Åsmund	SINTEF Energy Research	NORWAY
Galbiati	Alesandro	Wood Italiana S.r.l.	ITALY
Gogulance	Vlad	LUKOIL Neftochim Bourgas JSC	ROMANIA
Gregoire	Vincent	Equinor	NORWAY
Höwing	Jonas	Alleima	SWESEN
Ismail	Sheila	BP	UK
Monnot	Martin	Industeel	FRANCE
Noordink	William	Corrosion Radar	NETHERLANDS
Oskui	Ali	CorrosionRADAR Ltd.	UK
Patel	Niketan	Slovak Acadely of Science	SLOVAKIA
Rodriguez Jorva	Javier	CEPSA	SPAIN
Ropital	François	IFP Energies nouvelles	FRANCE
Scharsching	Christoph	OMV Refining & Marketing GmbH	AUSTRIA
Schempp	Philipp	TH Köln – University of Applied Sciences	GERMANY
Shinnosuke	Kurihara	Nippon Steel Corporation	JAPAN
Surbled	Antoine	A.S – CORR CONSULT	FRANCE
Tacq	Jeroen	SIRRIS	BELGIUM
Van Caelenberghe	Timothy	Fluves	BELGIUM
van Malsen	Johan	McDermott	NETHERLANDS
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Vassileva	Vassilka	OMV Refining & Marketing GmbH	AUSTRIA
Verner	Jan	ORLEN Unipetrol	CZECH REPUBLIC
Vosecký	Martin	Nalco Water	CZECH REPUBLIC
Warnier	William	Sitech	NETHERLANDS
Wold	Kjell	Sensorlink	NORWAY
Yuhei	Suzuki	Nippon Steel Europe GmbH	GERMANY
Zhang	Jian-Zhong	SABIC	UK
Zlatnik	Ivan	MITSUI & Co Deutschland	CZECH REPUBLIC

REMOTE			
NAME	**SURNAME**	**COMPANY**	**COUNTRY**
Astudillo	Miguel	CEPSA	SPAIN
Enegela	Philipp	INEOS Olefins & Polymers UK	UK
Groysman	Alec	Israeli Corrosion Forum	ISRAEL
Heider	Ben	Air Liquide Global E&C Solutions Germany GmbH	GERMANY
Kirchheiner	Rolf	MTI	GERMANY
Leone	Antonino	Eni	ITALY
Low	Philip	Rig-Tech Solutions	SPAIN
Maffert	Joerg	Dillinger Huttenwerke	GERMANY
Matthews	Dale	Zerust Oil andGas	SPAIN
Norling	Rikard	RISE Research Institutes of Sweden	SWEDEN
Sanchez	Sagrario	Dow	SPAIN
Sharma	Prafull	Corrosion RADAR	UK
Soltani	Askar	South Pars Gas Complex	IRAN
Thornthwaite	Philip	Baker Hughes	UK
Ulm	Philipp	Bayernoil Raffineriegesellschaft mbH	GERMANY
Wijnants	Geert Henk	STORK Asset Management Technology	NETHERLANDS
Zakeri	Hadi	PetroIneos	UK

Appendix 2

EFC WP15 Activities

(Francois Ropital)

EFC Working Parties

http://www.efcweb.org

- WP 1: Corrosion Inhibition
- WP 3: High Temperature
- WP 4: Nuclear Corrosion
- WP 5: Environmental Sensitive Fracture
- WP 6: Surface Science and Mechanisms of corrosion and protection
- WP 7: Education
- WP 8: Testing
- WP 9: Marine Corrosion
- WP 10: Microbial Corrosion
- WP 11: Corrosion of reinforcement in concrete
- WP 14: Coatings
- WP 15: Corrosion in the refinery and petrochemistry industry
  (created in sept. 96 with John Harston as first chairman)
- WP 16: Cathodic protection
- WP 17: Automotive
- WP 18: Tribocorrosion
- WP 19: Corrosion of polymer materials
- WP 20: Corrosion by drinking waters
- WP 21: Corrosion of archaeological and historical artefacts
- WP 22: Corrosion control in aerospace
- WP 23: Corrosion reliability of Electronics

- WP24: CO_2 Corrosion in industrial applications
- WP25: Atmospheric corrosion

- Task Force Corrosion in green energies applications → WP26 ?
- Task Force Corrosion of medical implants and devices

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

WP15 Was created in 1996 – Today 358 members .
Attendance to WP15 meetings and Eurocorr dedicated sessions 50-70 participants

Information Exchange – Forum for Technology

Eurocorr Conferences : organization of refinery session and joint session with other WPs

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

Publications - Guidelines : EFC "Green Books"

Chairman: Francois Ropital Deputy Chairman: Johan Van Roij

EFC decision: :Reelection for 3 years of Chairperson and Deputy Chair

New Chairperson and Deputy Chair (Secretary, Young Corrosion Delegate) are sought to lead WP15

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

Eurocorr Conferences : organization of refinery session and joint session with other WPs (2023 Brussels-Belgium, 2024 Paris-France)
In 2023 the Refinery corrosion session was on Monday 28 August 2023
In 2023 the Joint session on Biorefineries will be on Thursday 31 August 2023
In 2024 Eurocorr will take place from 1 to 4 September in Paris (France)
In 2025 Eurocorr will take place from 7 to 11 September in Stavanger (Norway)

WP Meetings
One WP 15 working party meeting in Spring
One meeting at Eurocorr in September in conjunction with the conference, this year it will be on Tuesday 29 August 2023 in Brussels (hybrid meeting)

Publications - Guidelines

Web site : https://efcweb.org/WP15.html

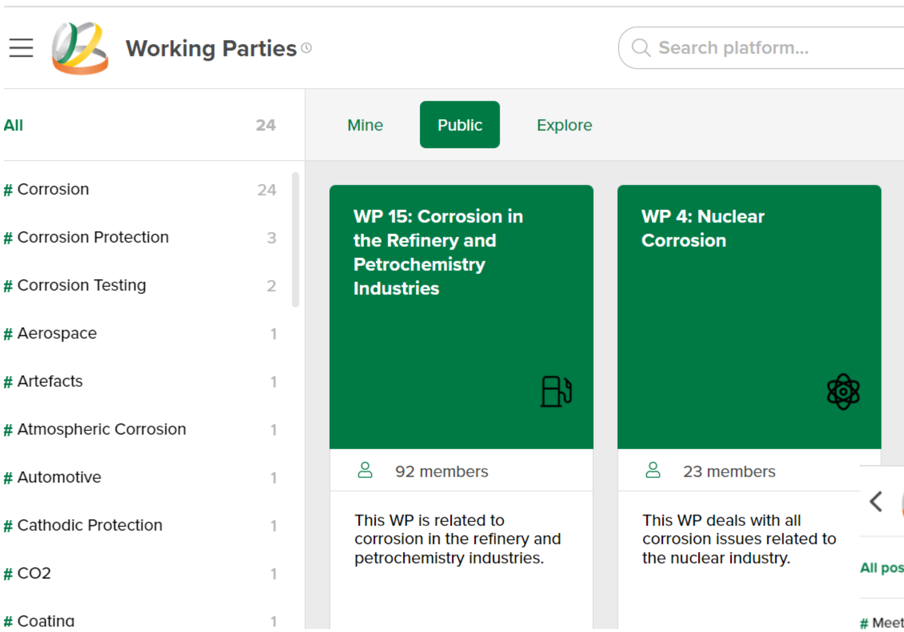
EFC Hub : https://efc.solved.fi/activities/wp/list

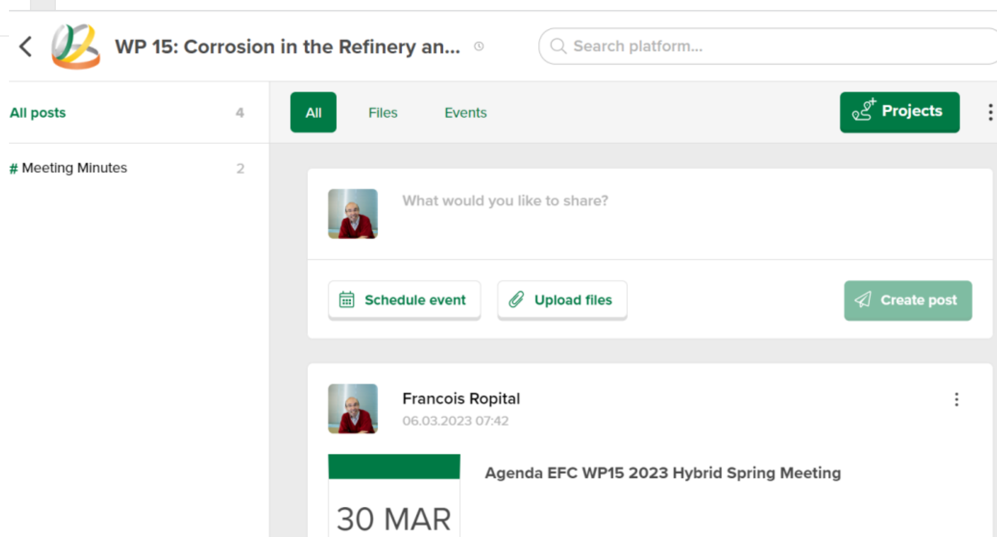
List of the WP15 spring meetings :

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
24 March 2022	Zoom meeting
30 March 2023	Lille - France (Nalco) + Zoom meeting

EFC Hub Platform

A Web forum platform on the EFC Hub platform has been created
https://efc.solved.fi/activities/wp/list

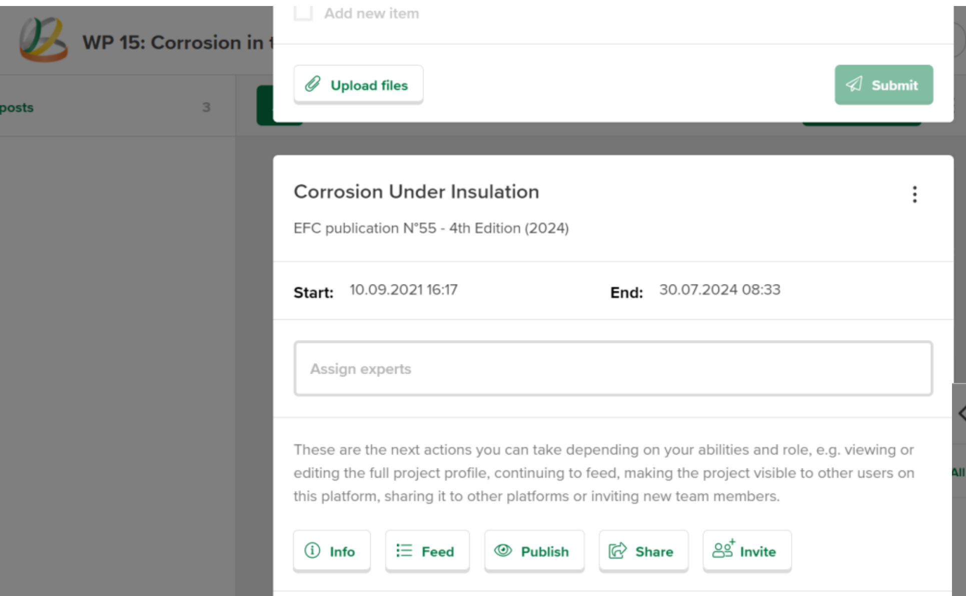


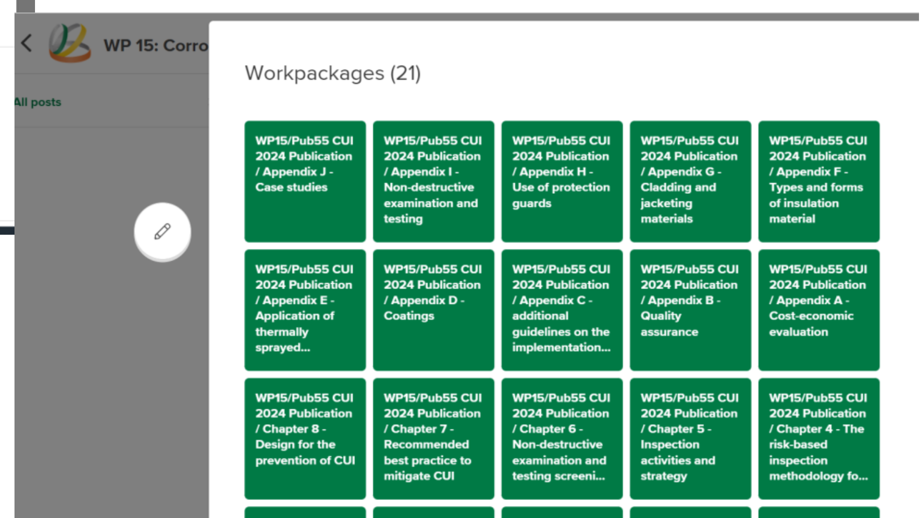


EFC Hub Platform: CUI Project

EFC CUI Web forum platform:

https://efc.solved.fi/activities/wp/feed/ef91a569-219e-444b-90f8-69c26945cdf7





Publications from WP15 – Forum Platform

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

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

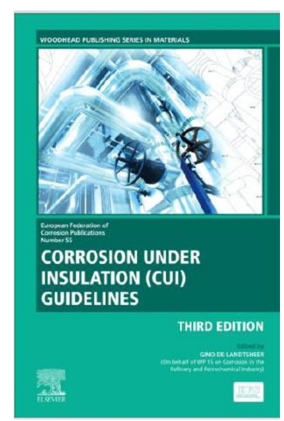
•EFC Guideline n° 46 revision on corrosion in amine units Editor: Johan van Roij
is now available

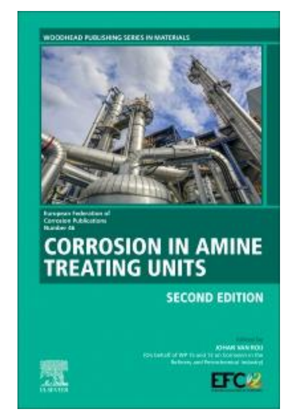
https://www.elsevier.com/books/corrosion-in-amine-treating-units/van-roij/978-0-323-91549-6

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

In progress by a task force

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/

EFC Hub Platform : https://efc.solved.fi/activities/wp/list

Information :
Future conferences related to refinery corrosion

3-7 March 2024
CORROSION 2023 AMPP New Orleans

1-4 September 2024
EUROCORR 2024 Paris France

7-11 September 2025
EUROCORR 2025 Stavenger Norway

Look at the Website: https://efcweb.org/Events.html

Appendix 3

Bio Refinery – Materials selection challenges

(Johan van Malsen)

BIO REFINERY– MATERIAL SELECTION CHALLENGES

Johan van Malsen

MCDERMOTT

- **Introduction**
- **Biorefinery**
- **Conventional Refinery – Naphthenic Acid Corrosion**
  - Material selection based on experience which is mainly covered in standards such as API
    - Reference API RP 571 Damage Mechanisms in the Refinery Industry
- **Is this applicable to Bio Refinery with high TAN numbers (almost 200)?**
- **Are same materials suitable, are same inhibitors suitable and/or required?**
- **What are the experiences?**

Feed composition Bio Refinery

- **Varying feed composition including used cooking oil and animal fat**

Bases for material selection:

UCO = Used cooking oil
TOFA = Tall Oil Fatty acid

TAN_{design} = 200 mg KOH/g

Chlorides: Organic or inorganic? For UCO, NaCl may be converted to organic Cl during pretreatment.

MDMT = -15°C

4.1 Feed properties

		UCO (Feed 1)	TOFA (Feed 2)
Rate	t/d	1000	1000
Density at 15°C	kg/m^3	921	908
Sulfur	ppmwt	0	1500
Nitrogen	ppmwt	0	750
Silicon	ppmwt		< 3
Free Fatty Acid	wt%	0.6	> 95
Acid no.	mg KOH/g	1.2	> 190
Moisture and Volatile matter	ppmwt	< 500	< 1000
Unsaponifiable Matter	wt%	1.0 (max)	<2
Insoluble impurities	ppmwt	50	< 200
Phosphorus	ppmwt	2 (max)	3 (max)
Chloride	ppmwt	15 (max)	20 (max)
Total Metals	ppmwt	5 (max)	8 (max)
Rosins	%wt	0	2

MCDERMOTT

What does API RP 571 tell us?

- **From API RP 571 chapter 3.7 on organic acids:**

The type and quantity of organic acids formed in the overhead system are crude specific. One source of these acids is believed to be the thermal decomposition of naphthenic acids in the crude, which may be precursors to light organic acid formation. In that case, the processing of higher total acid number (TAN) crudes might increase organic acid in the overheads. However, very little published information is available on this subject.

In general, light organic acids do not generate the severity of corrosion associated with inorganic acids such as HCl. Table 3-7-1 shows the HCl equivalent factor for corrosion by organic acids in overhead systems. To calculate the HCl equivalent of an organic acid, multiply the content of the organic acid (in weight ppm) by the factor for that acid, and the result will be the equivalent content of HCl (in ppmw). This number can then be used to estimate the additional neutralizer needed in the overhead system to compensate for the organic acids present. This must be done with caution, because excess neutralizer can lead to amine hydrochloride salts in overhead systems.

Table 3-7-1—Light Organic Acid Corrosion Equivalency Factors

Acid	HCl Equivalent Factor
Formic	0.76
Acetic	0.61
Propionic	0.49
Methyl propionic	0.41
Butanoic	0.41
3-methyl butanoic	0.36
Pentanoic	0.36
Hexanoic	0.31
Heptanoic	0.28

What does this mean for Fatty acids and resin acids of different lengths and masses?

- **From chapter 3.7 ctd.**

Corrosion caused by light organic acids in crude unit overhead systems can be minimized through the injection of an acid-neutralizing additive. However, problems may arise when frequent changes in crude blends lead to frequent changes in neutralizer demand.

The TAN of the crudes being processed can be used as an initial guide to determine the neutralizer requirement. If the crude TAN increases, one should anticipate an increase in the acid concentration in the overhead system.

3.46.2 Affected Materials

Carbon steel, low-alloy steels, 400 series SS, 300 series SS, and nickel-based alloys.

3.46.3 Critical Factors

a) Naphthenic acid corrosion (NAC) is a function of the naphthenic acid content, temperature, sulfur content, velocity (wall shear stress), and alloy composition.

b) Severity of corrosion increases with increasing acidity of the hydrocarbon phase.

c) Neutralization number or TAN is a measure of the acidity (organic acid content) as determined by various test methods such as ASTM D664. However, NAC occurs in hot dry hydrocarbon streams that do not contain a free water phase.

d) The TAN of the crude may be misleading, because the correlation between whole crude TAN and corrosion rate is poor, especially when comparing different crudes. A high TAN crude may be less corrosive than a moderate or low TAN crude. This is because this family of organic acids that together are referred to as naphthenic acid, has a range of boiling points and tends to concentrate in various cuts. Therefore, the occurrence and severity of NAC are determined by the naphthenic acids present in the actual stream, not the crude charge. Additional factors are the following.

   1. TAN is a measure of the total amount of all acids in the crude, not just naphthenic acids.

   2. The various acids that comprise the naphthenic acid family can have distinctly different corrosivity.

   3. The structure and molecular weight of the specific naphthenic acids present have a strong impact on corrosivity, but they are not determined by TAN measurements.

e) No widely accepted prediction methods have been developed to correlate corrosion rate with the various factors influencing it.

API RP 571 on NAC

f) Sulfur promotes iron sulfide formation and has an inhibiting effect on NAC, up to a point.

g) Naphthenic acids remove protective iron sulfide scales on the surface of metals.

h) NAC can be a particular problem with very low sulfur crudes. While a crude TAN threshold of 0.30 is typically cited as the TAN level below which NAC is not expected, some NAC cases have been reported with low sulfur and crude TAN as low as 0.10.

i) NAC primarily occurs in hot streams above 425 °F (220 °C) but has been reported as low as 350 °F (175 °C). Severity increases with temperature up to about 750 °F (400 °C); however, NAC has been observed in hot coker gas oil streams up to 800 °F (425 °C).

j) Naphthenic acids are destroyed by catalytic reactions in downstream hydroprocessing and FCC units. NAC of 300 series SS is also inhibited by injection of hydrogen in the feed to hydroprocessing units.

k) Alloys containing increasing amounts of molybdenum show improved resistance to NAC. While alloys with a minimum of 2 % Mo, e.g. Types 316 and 316L SS, have demonstrated adequate resistance in some applications, it is generally agreed based on industry experience that alloys with a minimum of 3 % Mo, e.g.

Types 317 and 317L SS, are needed avoid NAC. To provide a greater degree of assurance, alloys with a minimum of 4 % Mo, e.g. Type 317LM, are sometimes selected. Under severe conditions or for components with nil corrosion allowance, 6 % Mo stainless steels and Alloy 625 have been used.

l) Corrosion is most severe in two-phase (liquid and vapor) flow, in areas of high velocity or turbulence, and in distillation towers where hot vapors condense to form liquid phase droplets.

1. For piping, NAC typically occurs in high-velocity and turbulent areas. The vapor space may be more susceptible to corrosion when flow is two phase due to acid condensation.

Materials suitable for NAC as per API RP 571

Table 3-46-1—Alloys Listed in Approximate Order of Increasing Resistance to NAC

CS, 1¼Cr-½Mo, 2¼Cr-1Mo,
5Cr-½Mo
9Cr-1Mo, 410 SS, 304L SS, 321 SS, 347 SS
316 SS (2 % to 3 % Mo)
317 SS (3 % to 4 % Mo)
6 % Mo alloys
Alloy 625, Alloy 276
NOTE Alloys listed above 316 SS in the table are not considered NAC-resistant materials.

With more aggressive fatty acids compared to naphthenic acids, the range of suitable materials may be limited and the red shaded area may need to be expanded to include all austenitic stainless steel grades?

Experiences?

Questions and discussions

- **Is RP 571 for NAC also applicable to Bio Refinrey with fatty acids with high TAN numbers (almost 200)?**
- **Are same materials suitable, are same inhibitors suitable and/or required? And is amount of inhibitor to be adjusted for changes in feed type/compositions? How is this controlled?**
- **Hydrogen is understood to inhibit NAC. Would this also be applicable to fatty acids?**
- **Are there experiences that can be shared by the audience?**

Appendix 4

COST Network European Funding

(Francois Ropital)

- Intergovernmental programme (established in 1971) dedicated to funding European and international research and innovation networks

- Structuring a Europe-wide network

- Especially on new, interdisciplinary topics (networking of communities that interact little)

- Especially for topics not covered by collaborative calls in Horizon Europe

- Only networking activities are funded (not salaries)

- At least 7 participating member **countries** (on average, 15-20 per network) including **at least 50% of JTIs (inclusiveness targeted countries)**

Example:

	Budget (Work and Budget Plan)	Actual Eligible Expense (Financial Report)
Meetings	EUR 55.000,00	EUR 54.500,00
Training Schools	EUR 20.000,00	EUR 19.500,00
STSM	EUR 30.000,00	EUR 28.750,00
VM	EUR 4.000,00	EUR 4.000,00
Presentation for capacity building	EUR 3.000,00	EUR 2.500,00
Presentation for dissemination	EUR 1.500,00	EUR 1.000,00
Dissemination and Communication Products	EUR 10.000,00	EUR 12.000.00
OERSA	EUR 2.934,78	EUR 1.800,00
VNS	EUR 4.000,00	EUR 4.000,00
SUB TOTAL	**EUR 130.434,78**	**EUR 128.050,00**
FSAC	**EUR 19.565,22**	**EUR 19.207,50**
TOTAL	**EUR 150.000,00**	**EUR 147.257,50**

Network on Corrosion in Biorefineries

COST Members

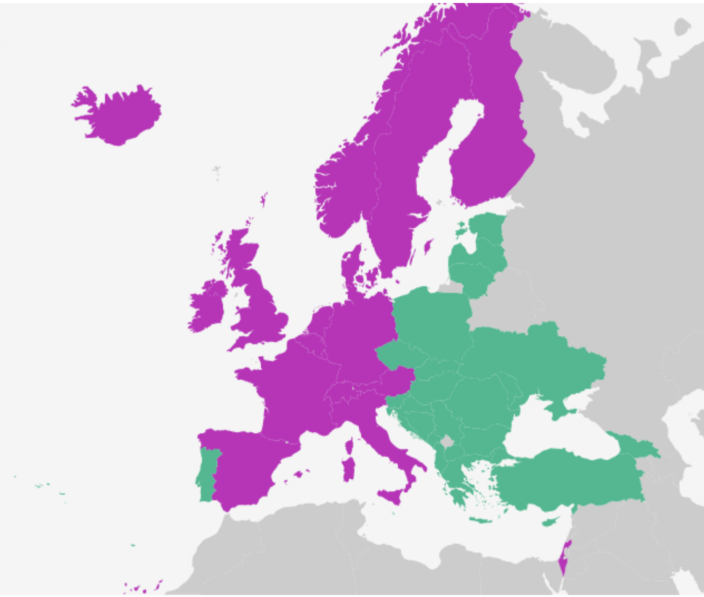
The 40 COST Members are: Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Republic of Moldova, Montenegro, The Netherlands, The Republic of North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, and United Kingdom.

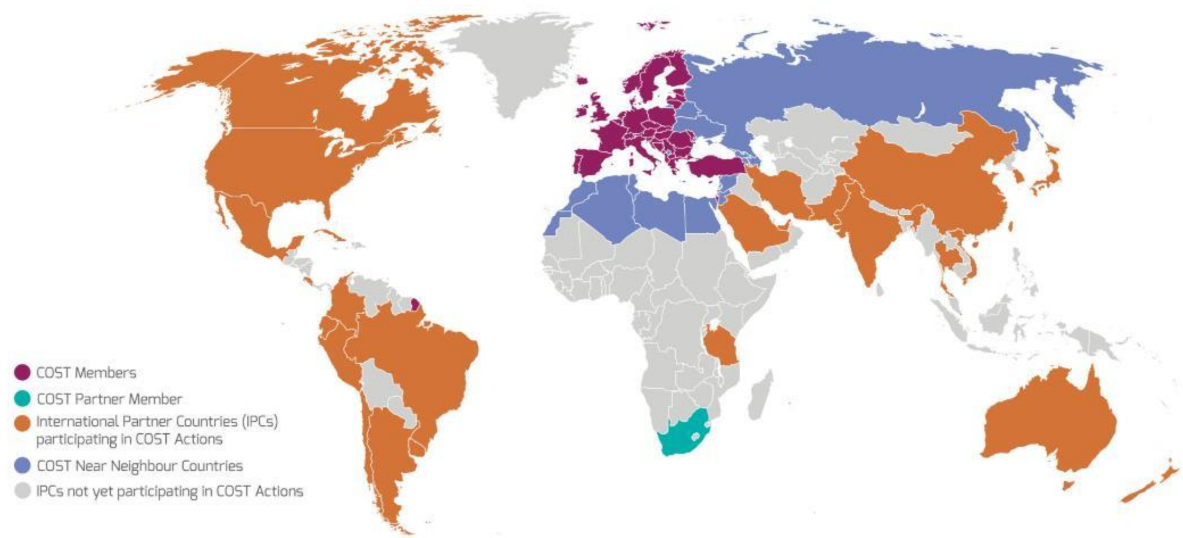
Cooperating Member

Israel is a Cooperating Member. A Cooperating Member implies non-voting rights in the COST CSO. However, researchers from COST's Cooperating Member enjoy member rights in COST Action participation.

Partner Member

South Africa is a Partner Member. A Partner Member implies no rights to attend the COST CSO. However, researchers from COST's Partner Members enjoy observer rights in COST Action participation.





Appendix 5

Prediction of Materials Degradation by using Big Data and Machine Learning

(Philipp Schempp)

Proposal: Prediction of Material Degradation

…on basis of Big Data and Machine Learning

WP15 meeting @ Eurocorr 2023 (Brussels, 2023-08-29)

Philipp Schempp, Prof. Dr.
TH Cologne - University of Applied Sciences

Technology Arts Sciences TH Köln

Big Integrity Data

Nitrogen

Pour point

Dosing rate

Salts

Total sulphur

Throughput

H_2S

Conductivity

Flow rate

Metal temperature

Pressure

Mercaptans

Chlorides

ppH_2

S/TAN ratio

Liquid level

Acid number

Valve position

Flow velocity

pH

Filter residue

Exothermic heating

Coking tendency

Temperature

Density

Vapour pressure

Flash point

Differential pressure

Acid loading

Residual base

Free water

CO_2 loading

NaOH

Reflux ratio

Corrosion rate

Oxygen

Dew point

Mechanical amplitude

Hydrocarbons

Flow regime

Cyanides

Philipp Schempp, Prof. Dr.
TH Cologne - University of Applied Sciences

Big Integrity Data

Nitrogen
WEEKLY

Pour point
DAILY

Dosing rate
EVERY MINUTE

Salts
WEEKLY

Total sulphur
DAILY

Throughput
EVERY SECOND

H_2S
MONTHLY

Conductivity
DAILY

Flow rate
EVERY SECOND

Metal temperature
EVERY MINUTE

Pressure
EVERY MINUTE

Mercaptans
WEEKLY

Chlorides
WEEKLY

ppH_2
MONTHLY

S/TAN ratio
WEEKLY

Liquid level
EVERY MINUTE

Acid number
DAILY

Valve position
EVERY MINUTE

Flow velocity
EVERY SECOND

pH
WEEKLY

Coking tendency
WEEKLY

Temperature
EVERY SECOND

Filter residue
WEEKLY

Exothermic heating
EVERY SECOND

Density
DAILY

Vapour pressure
EVERY SECOND

Differential pressure
EVERY MINUTE

Acid loading
WEEKLY

Flash point
WEEKLY

Residual base
YEARLY

Free water
DAILY

CO_2 loading
WEEKLY

Corrosion rate
MONTHLY

NaOH
DAILY

Reflux ratio
EVERY MINUTE

Oxygen
EVERY MINUTE

Dew point
HOURLY

Mechanical amplitude
EVERY SECOND

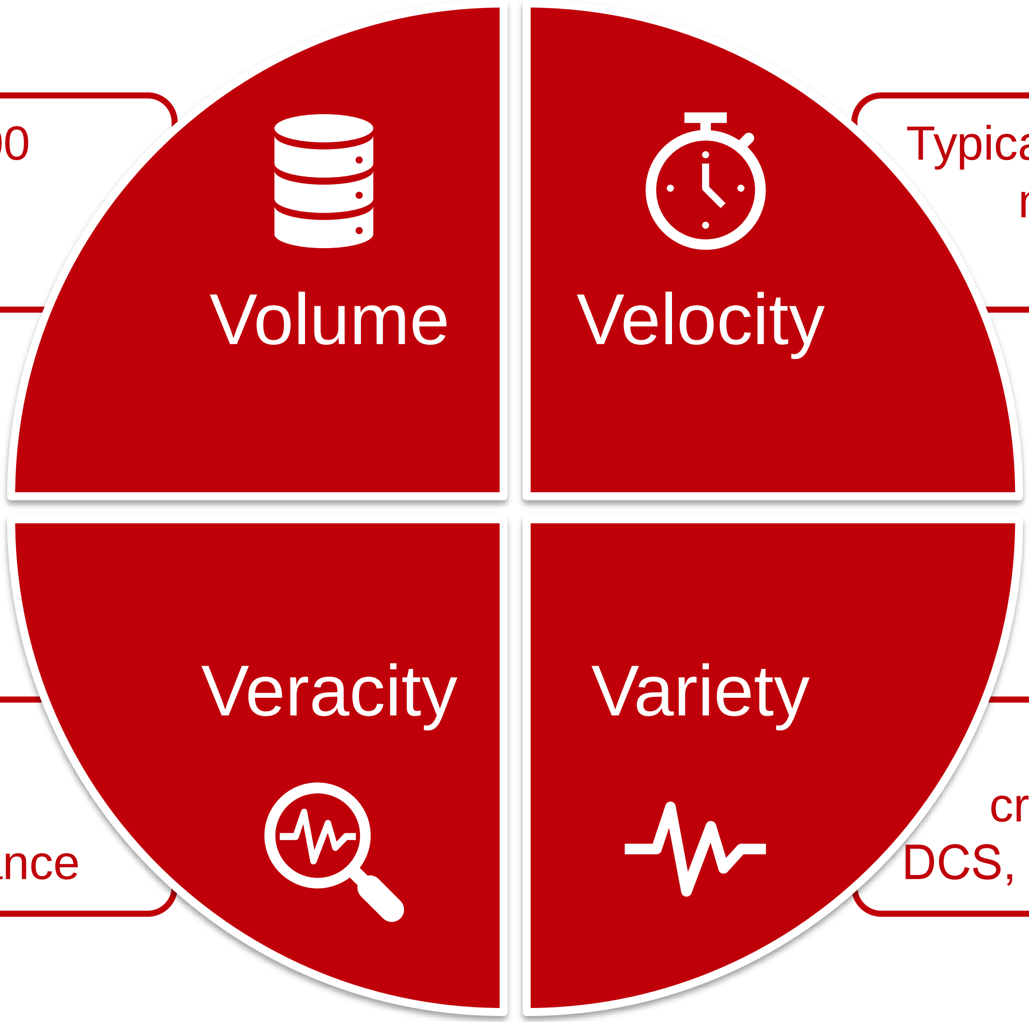
Hydrocarbons
DAILY

Flow regime
EVERY MINUTE

Cyanides
YEARLY

Big Data – the *“4 Vs”* with examples from process industry

Typically, > 10.000 measuring para-meters per site



Typically, > 15.000.000 measuring values per site per day

Data quality, model validation, and user acceptance

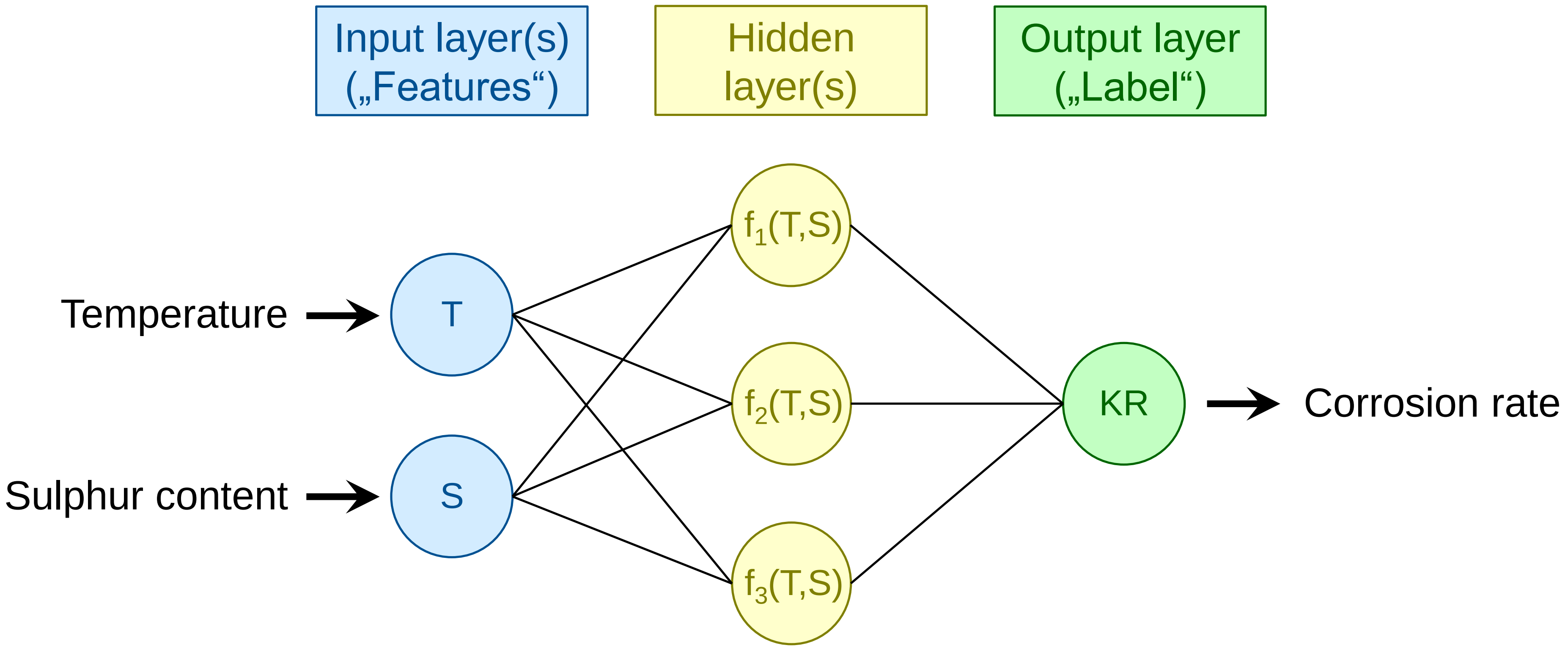
IMS, RT images, crude oil database, DCS, Pi, SAP, Excel,…

Machine learning (ML) with neural networks

1st step (preparation): Neurons in hidden layer(s) calculate output from input parameters

2nd step (training): Adjustment of neurons according to <u>known</u> combinations of input/output

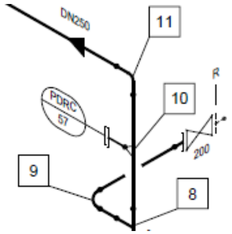
3rd step (prediction): Model generates output on basis of <u>unknown</u> input

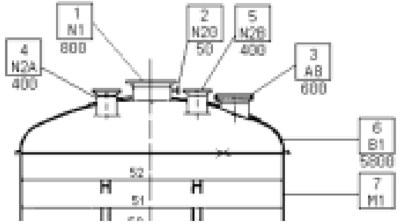


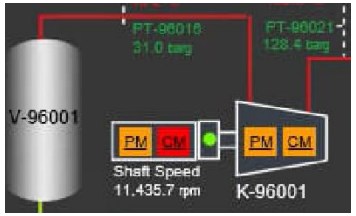
Typical, digitally available integrity data

Input

Type of data	Source	No. of data points
Inspection isometrics piping	pdf	> 10.000
Inspection schemes vessels	pdf	> 10.000
Equipment specs	IMS	> 1 million
Process parameters (T, pH,…)	PI / DCS	> 1.000

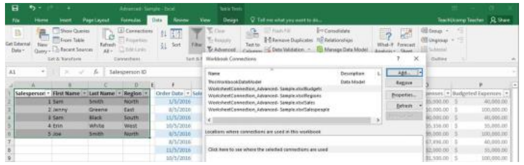






Output

Type of data	Source	No. of data points
UT/RT wall thickness readings	IMS / Excel	> 10 million
Digital RT images	jpg	> 1 million
Inspection history	IMS	> 100.000
Data on LOPCs, near leaks etc.	IMS / Excel	> 1.000



Suggested approach

Ask the important questions in correct order

- 1st question: *“Where does material degradation hurt us most?”*
  (goal: minimise LOPCs + UPDT and maximise personal + process safety)

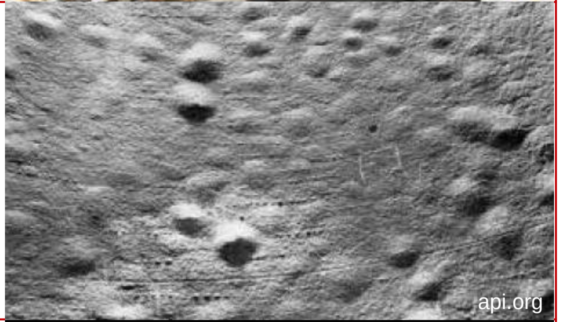
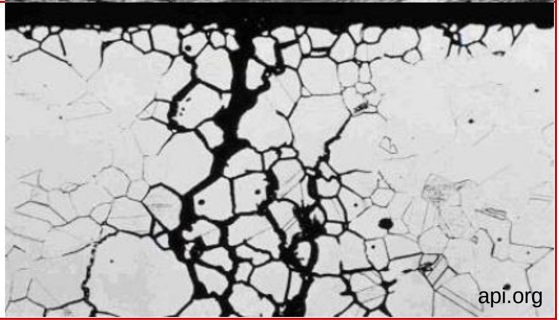
- 2nd question: *“Do we have appropriate data digitally available?”*
  (goal: data covers most important influencing parameters, e.g. temperature)

- 3rd question: *“Is such data sufficiently clean and reliable?”*
  (goal: sufficient data remaining after cleaning)

Philipp Schempp, Prof. Dr.
TH Cologne - University of Applied Sciences

Suggested approach

3 simple examples

Mechanism	Example	Big Data availability	Appearance
Corrosion	Sulphidation	Temperature Sulphur content Flow velocity Flow regime	
Hydrogen damage	Hydrogen Blistering	Temperature H_2S concentration pH Hardness	
Cracking	Stress corrosion cracking	Temperature Impurities pH Mechanical loads	

Example: CUI prediction

State of the art

- Industry
  - 30% of all corrosion failures in process industry are due to CUI [Wu 2013]
  - 40-60% of pipe repair costs are due to CUI [Wilds 2017]
  - CUI remains difficult to predict → industry tends to <u>preventive</u> instead of <u>predictive</u> maintenance

- Public sources
  - Several studies predicted CUI corrosion rates based on <u>empirical API data</u> [Mohsin 2019]
  - CUI standards from ASTM, NACE, API etc. do not involve ML so far [Eltai 2019]
  - Much effort on ML-assisted corrosion prediction in other areas, e.g. aqueous corrosion in oil & gas pipelines [Al-Sabaeei 2023]

→ Large potential for CUI prediction <u>using ML on basis of actual site data</u>

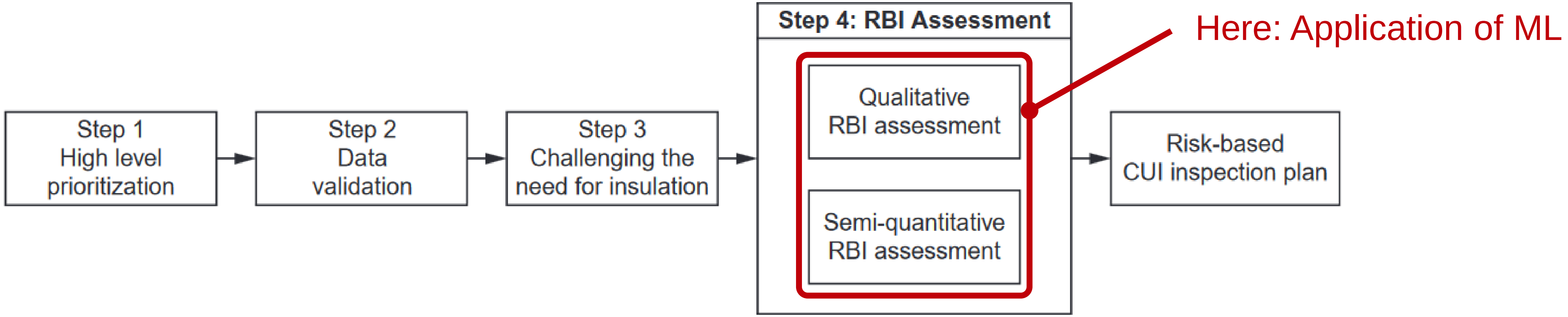
Example: CUI prediction

RBI and Machine Learning (ML)

- ML cannot replace RBI but is an important extension
- ML model can provide likelihood to CUI
- Potential consequences to be derived from RBI

→ risk assessment

→ Suggestion: ML can be embedded into CUI inspection plan development as recommended by EFC Technical Guide 55 [De Landtsheer 2020]:



Example: CUI prediction

Typically covered by RBI

INPUT / FEATURES	
Parameter	**Source**
Material	IMS
Operating temp.	IMS
Coating condition	? (to be assumed)
Insulation condition	? (to be assumed)
Heat tracing	P&IDs
Environment	Internet

Philipp Schempp, Prof. Dr.
TH Cologne - University of Applied Sciences

Example: CUI prediction

Typically covered by RBI

Potential ML extension

INPUT / FEATURES

Parameter	Source
Material	IMS
Operating temp.	IMS
Coating condition	? (to be assumed)
Insulation condition	? (to be assumed)
Heat tracing	P&IDs
Environment	Internet
Actual operating temp.	PI / DCS
Operating temp. history	PI / DCS
> 20 design specs (e.g. DN)	IMS
Equipment complexity	Isometrics / drawings
Equipment location / exposure	GPS / digital twin
CML location / exposure	Isometrics / drawings

OUTPUT / LABELS

Parameter	Source
Inspection history	
WT measurements, CUI sensors	IMS
D(RT) images indicating CUI	IMS
Historical inspection reports	IMS
Maintenance history	
Inspection schedules due to CUI	IMS
Coating activities	SAP
Insulation activities	SAP
QM notifications due to CUI	SAP
Maint. activities due to CUI	SAP
Failure history	
LOPCs due to CUI	IMS / Excel

Example: CUI prediction

Result

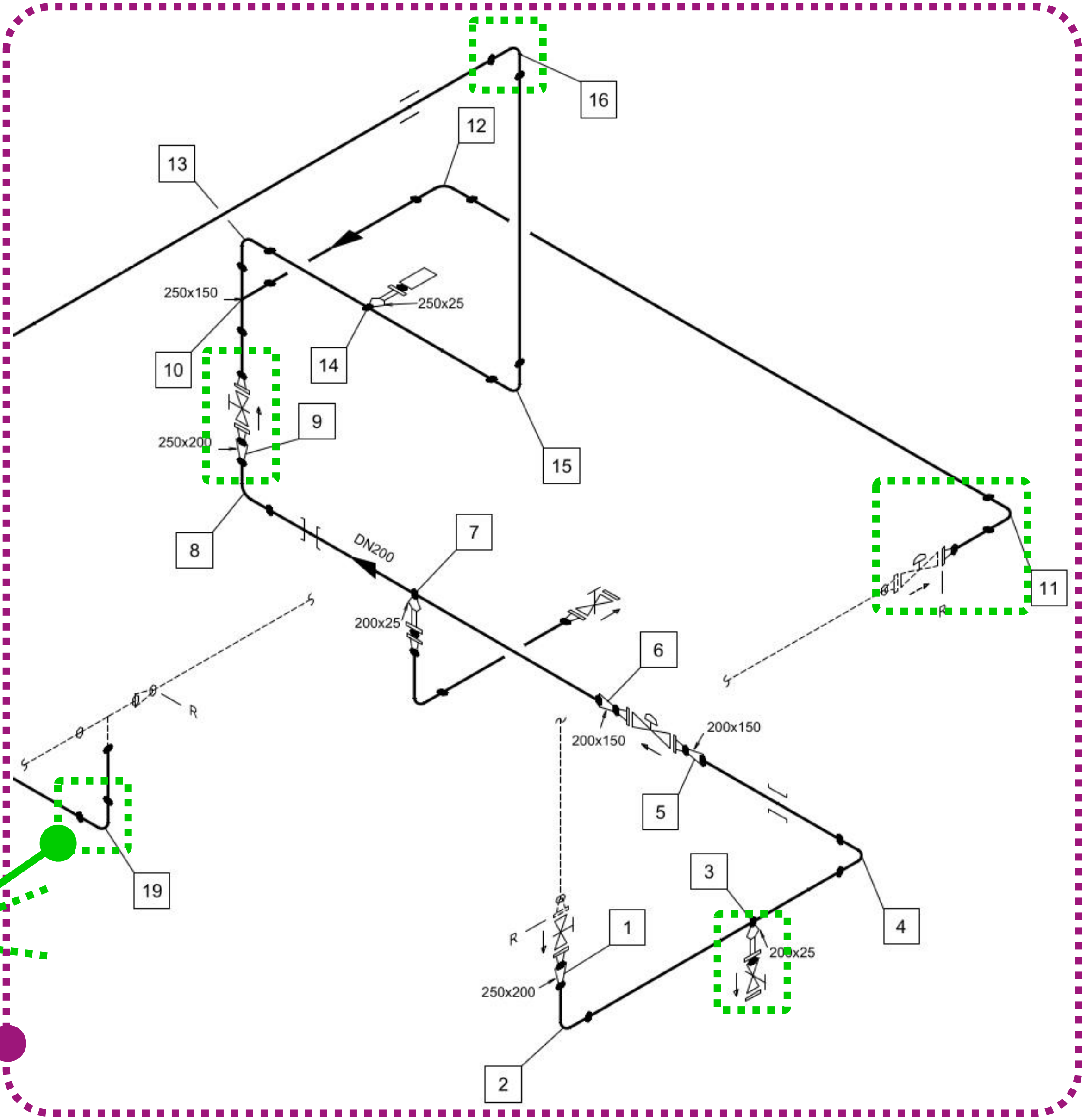
- Probability of CUI and local corrosion rate

Resolution

- ML allows to increase resolution from <u>equipment</u> to <u>CML</u> level

→ No <u>preventive</u> de-insulation + inspection of entire piping but <u>predictive</u> maintenance

→ **Opportunity to significantly reduce costs and improve safety**



ML inspection scope

RBI inspection scope

Example: CUI prediction

Potential

- ML models provide the chance to really make one large step ahead in CUI prediction by
  - …getting better and better (training effect)
  - …detecting complex patterns
- Simple example:
  - Coating quality = one of the most important contributing factors but often unknown
  - Model output: *"High susceptibility to CUI of Cr steel DN 150 pipe elbows in unit CDU-1"*
  - Underlying reason: Such elbows coated 15 years ago by same worker who did a poor job…

Typical challenges

- Model validation
- Model limitations, e.g. resolution + coverage
- Combine prediction with proper inspection (e.g. moisture detection) and maintenance (e.g. TSA)

How TH Cologne can support you

Philipp Schempp
Professor for Materials Application
Institute of Applied Materials (IWA)
TH Köln, Cologne, Germany
Philipp.schempp@th-koeln.de

Our offer

- New R&D area: Prediction of material degradation
- Project funding
  - Public funding (paid by TH Köln)
  - Contract research (paid by cooperating company)
- 10y expertise in materials & corrosion & integrity management in major oil & gas company (Philipp) + support by data scientists (colleagues from TH Köln)

Opportunities for industry

- "Find the leak before it happens" → improve your asset integrity and reduce costs
- Save money by outsourcing R&D activities your staff does not have time for
- Join the AI journey towards more innovative solutions and to secure your site`s future

→ Currently looking for industry partners / just contact me in case of interest / happy to support ☺

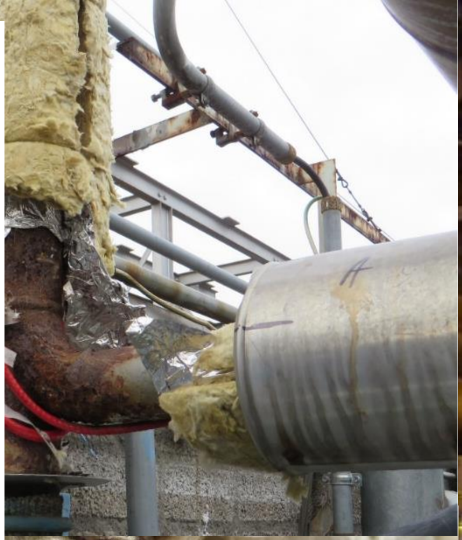
Literature

- [Al-Sabaeei 2023]: A.M. Al-Sabaee et al., “Prediction of oil and gas pipeline failures through machine learning approaches: A systematic review”, Energy Reports, Vol. 10, 2023, pp. 1313-1338.
- [De Landtsheer 2020]: De Landtsheer, G., “Corrosion Under Insulation (CUI) Guidelines – Technical Guide for Managing CUI”, 3rd ed., 2020, EFC publication No. 55, Woodhead Publishing, Sawston, UK.
- [Eltai 2019]: E.O. Eltai, F. Musharavati and E. Mahdi, “Severity of corrosion under insulation (CUI) to structures and strategies to detect it”, Corrosion Reviews, Vol. 37, No. 6, 2019, pp. 553-564.
- [Mohsin 2019]: Khan Muhammad Mohsin et al., “A fuzzy logic method: Predicting corrosion under insulation of piping systems with modelling of CUI 3D surfaces”, International Journal of Pressure Vessels and Piping, Vol. 175 (August), 2019, article 103929.
- [Wilds 2017]: Wilds N., “Corrosion under insulation”. In: Energy Trends in Oil and Gas Corrosion Research and Technologies, Woodhead Publishing, 2017, Duxford, UK, pp. 409–429.
- [Wu 2013]: W. Wu, G. Cheng, H. Hu, and Q. Zhou, "Risk analysis of corrosion failures of equipment in refining and petrochemical plants based on fuzzy set theory“, Engineering Failure Analysis, Vol. 32, 2013, pp. 23-34.

Appendix 6

Recent developments on “control on CUI” as per WCM initiative

(Geert Henk Wijnants)



STATUS OVERVIEW.

Corrosion under Insulation

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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 it yields best profits.
- Taking into account the continuation of 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

Development CUI Awareness tool
- Self assessment tool.
- Awareness w.r.t. CUI
- Evaluation level of robustness in terms of being prepared for CUI

Development Best Practice
- Modular set of tools for implementation of CUI management
- Risk based approach
- Based on the ISO HLS structure
- Standard based on hands-on experience of involved companies and the current state of the art in this matter.

Innovations project
- Development moisture-sensoring
- Development sustainable coatings with enhanced CUI resistance
- Development Best Practise CUI conscious insulating
- Determination of earning capacity CUI program for the industry.

Knowledge & Validation Project
- Performance of new detecting techniques
- Performance of new coatings
- Performance of improved insulation techniques
- Performance optimised CUI management as per industry branch

Upgrade feasible innovations
- Branch oriented innovations for proven performance blockers as per industry.
- Implementation service concepts for integrated CUI performance management (isolation, coating, inspection, energy efficiency)

Sustainable Control on CUI.

RISC

2018 2019 2020 2021 2022 2023

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Status of affairs:

Development English version for the Best Practise

	• Best Practise handbook	Finalized	ISO_High_Level_Structure_CUI(EN).pdf
	• Tool prioritization	Finalized	ToolBP_CuiManagementPrioritization(EN).xlsx
	• Tool risk assessment	Finalized	ToolBP_CuiManagement(EN)(Jan22).xlsx
	• Tool corrosion model	Finalized	BPSectionCorrosionModel.xlsx
	• Gap-analysis tool	Finalized	GAP_Analysis_TOR_BP_CUIManagement(EN).xlsx
	• Inspection- selection tool	Finalized	Tool Suitable NDT techniques(EN).xlsx
	• Presentation for rollout approach on a site	Finalized	WCM RB CUI Management(20Nov19)(EN).pptx
	• Life Cycle Costing tool	Finalized	Lifecycle costing CUI management(V2.4)(EN).xlsx
Q2 2023	• Strategy for CUI management	Finalized	DeStrategischeAanpakVoorEffectiefCOI_Management.pdf
Q2 2023	• CUI Condition monitoring reference model	Finalized	WorldClassMaintenance BestPractiseCUI_MonitoringStrategie(NL).pdf

Tooling made available through WCM website via WCM Vector; https://www.wcmvector.com/

Development Eco-system

• Separate website (EN) with gap-analysis developed	Finalized
• Q&A / ask the expert still to develop.	Being developed
• Development expert-group for new technologies	Ongoing

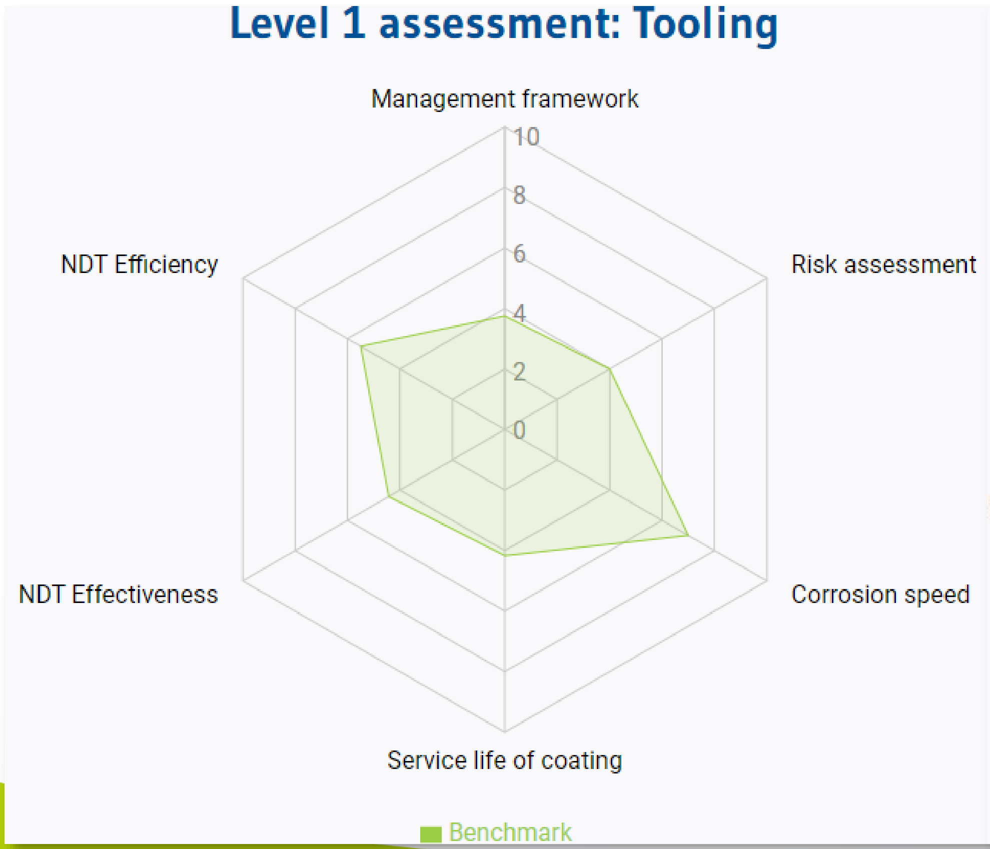
CUI-projects

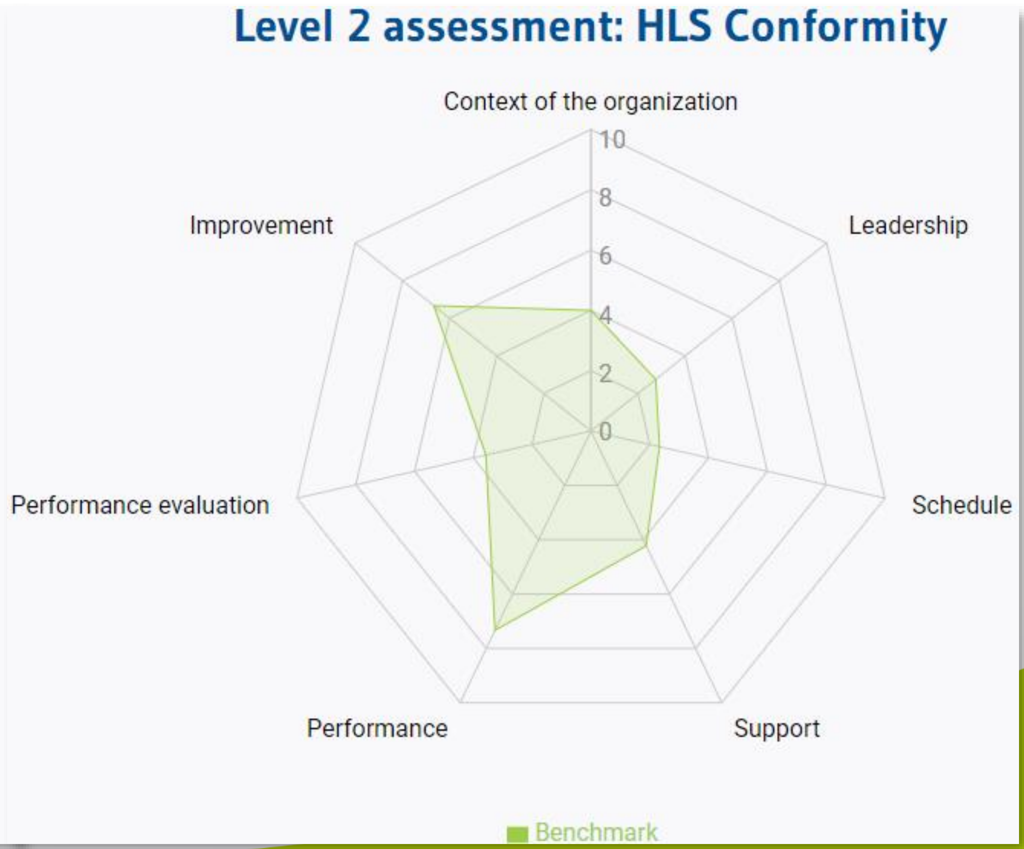
• Cooperation with KicMPI on behalf of validation process for CUI-protection-lifetime	Ongoing
• Best practise isolation condition assessment – commissioning & as-used.	Finalized
• – incl. EED (Energy Efficiency Directive) assessment.	Finalized

Status with respect to the application of tooling:

GAP-Analysis tooling: 4 companies; 5 audits; all “Chemicals”.

Benchmark score: 4+; exception Leadership and planning. => First profits to be obtained.





Background

Best Practice available since the end of 2019.

- Set-up in accordance with ISO HLS structure.
- Audit points included in the design.
- Assessment along two lines:
  - o Management line (HLS)
  - o Contents line (Critical elements)

  ➔ Probability of failure; average / max. / min.
- Consequences from std. risk model EN16991.

  ➔ Risk assessment and earning capacity.

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Risk-

Best Practice Risk Based CUI Management (BP RB-CUI).

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- te bewerkstelligen dat het RB-CUI-managementsysteem zijn beoogde resulta(a)t(en) behaalt;
- mensen aan te sturen en te ondersteunen om een bijdrage te leveren aan de doeltreffendheid van het RB-CUI-managementsysteem;
- continue verbetering te bevorderen;
- andere relevante managementfuncties te ondersteunen om hun leiderschap te tonen binnen hun verantwoordelijkheidsgebieden.

OPMERKING Waar 'bedrijfs' staat, wordt dit volgens de HLS structuur ruim geïnterpreteerd als de activiteiten die wezenlijk zijn gezien de doelen waarvoor de organisatie bestaat.

5.2 Beleid

[Δ9] De directie heeft een beleid vastgesteld dat:

a) passend is voor het doel van de organisatie;
b) een kader biedt voor het vaststellen van RB-CUI-doelstellingen;
c) een verbintenis bevat om te voldoen aan van toepassing zijnde eisen;
d) een verbintenis bevat tot continue verbetering van het RB-CUI-managementsysteem.

[Δ10] Het RB-CUI-beleid is daartoe:

- beschikbaar als gedocumenteerde informatie;
- wordt gecommuniceerd binnen de organisatie;
- is beschikbaar voor belanghebbenden, voor zover van toepassing.

5.3 Rollen, verantwoordelijkheden en bevoegdheden binnen de organisatie

De directie heeft bewerkstelligd dat de verantwoordelijkheden en bevoegdheden voor relevante rollen zijn toegekend en gecommuniceerd binnen de organisatie.

[Δ11] De directie heeft de verantwoordelijkheden en bevoegdheden toegekend met betrekking tot:

a) het bewerkstelligen dat het RB-CUI-managementsysteem voldoet aan de eisen van deze internationale HLS standaard voor beheersing van managementprocessen;
b) het rapporteren over de prestaties van het RB-CUI-managementsysteem aan de directie.

De verdeling van verantwoordelijkheden is in de volgende figuur weergegeven:

Senior Management	• Laten blijken van betrokkenheid / cultuur van voortdurende aandacht • Het ter beschikking stellen van personen & budget
Technische Staf/ Engineering	• Zekerstellen van correct ontwerp van nieuw equipment • Zekerstellen van representatieve asset conditie weergave • Initiëren van correctieve acties waar noodzakelijk
Maintenance	• Uitvoeren van noodzakelijke projecten • Zekerstellen van de kwaliteit van projecten
Operaties	• Bijtijds melden van defecten in de isolatie en/of stoom tracing • Vermijden van het beschadigingen van isolatie
Eigen Inspectiedienst	• Uitvoeren van inspecties waar noodzakelijk • Aanleveren van informatie voor het asset conditie overzicht

Figuur 1: Verdeling van verantwoordelijkheden voor het RB-CUI Management.

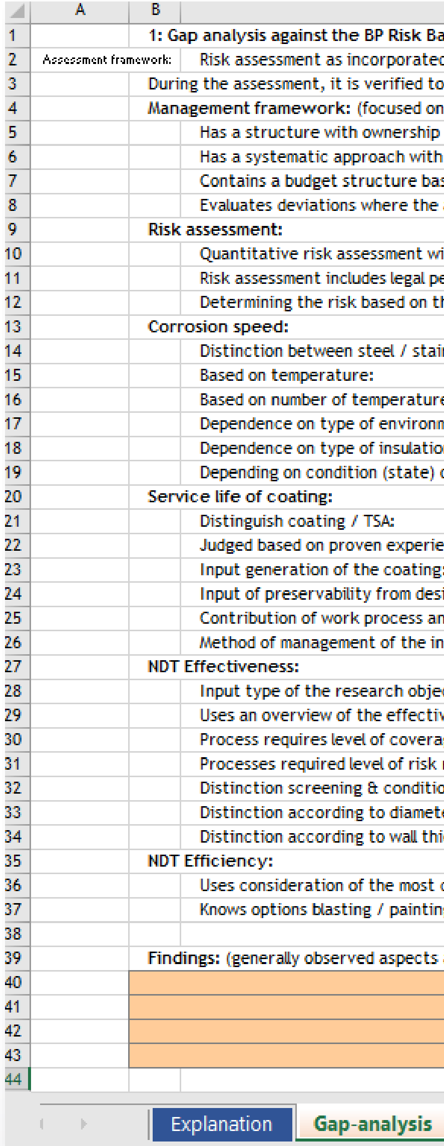
Uitbesteding: De genoemde verantwoordelijkheden zijn door middel van rollen binnen de eigen organisatie belegd. Vanuit die rol kunnen taken worden uitbesteed. Dit betreft: Uitvoering van projecten, uitvoeren van inspecties en genereren van rapportages. De aansturing van deze taken kan desgewenst ook worden uitbesteed als daarbij voldaan is aan de kwaliteitseisen van de eigen organisatie. Dit omdat de uiteindelijke verantwoordelijkheid voor de kwaliteit van het beheer bij de eigen organisatie berust.

File: ISO_HLS_BP_CUI_Management.docx Versie: 10 Bladzijde 7 van 15.

Corrosion under Insulation

First results based on the development.

- Choice for limited detail:
  “Stoplight” : Good/Average/Bad.
  It’s about the insight, not about discussing whether it’s a 4 or a 7.
- Large differences in one company depending on role/position
- Characteristic: “no policy implemented”
- Communication is essential.



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Next steps in development.

Based on the overview obtained from the internet application.

With that:

- Benchmark as steering tool to optimize from overall perspective.
- Create awareness to tackle the largest management gaps.
- Being able to follow one's own development (trend!) to monitor the effectiveness of the path followed.

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Application of the tooling developed:

Application often takes place as originally intended:

1. Use whatever complements the existing approach ☑
   a) Application condition classification (Huntsman) ☑
   b) Overall Application (Delamine) ☑
   c) Fitting parts as a supplement (Shell Catalysts -BE) ☑
2. Applying takes time and is not yet a priori time (among other tasks) ☑
3. From international framework pos. response to open concept (Kaefer) ☑
4. Introduced as best practice for the EFC55 update. ☑

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Status wrt the expert group New Technologies:

Currently 5 experts from div. background involved; NDT; Asset owner(2); Corrosion; Asset management

List with new technologies prepared. Pre selection TRL_BRL / Classification / Review / Final.

New CUI screening detection technology.

Toelichting op header (regel hieronder):

SELECTIE:	Technologie:	Leverancier:	Meet methode:	Data acquisitie:	Website:	Atex proof:	Praktijkcase:	Screening / Detectie-Evaluatie:	True positiv es:	False calls:	False negativ es:	Toepassin g	Onder- of op de isolatie.	Data verversing.	Eigen gebruik / data as a service (huur)	Onderhoud-gevoeligh	Communicatie (data	Kosten (indicatief):	Conclusie:	Klas
J	Signaal absorbtie & corrosie draad	CorrosionRadar	Fuse wire; Electromagnetic waves through wire; Aanbrengen draad onder de isolatie.	Wifi/Cellular/WirelessHART/LoRa	https://www.corrosionradar.com/	Ja; Zone 1 (II 3 GD cert.)	Ntb	Screening; vochtdetectie via radar reflectie & corrosiemeting via corrosie van de	Ntb	Ntb	Ntb									
J	Optische draad die per meter verschil qua uitzetting meet.	Fluves	Optical fibre moisture measurement; Aanbrengen draad OP de isolatie.		www.fluves.com.	?	manager BASF; blijkt bij afpellen een student te zijn die 4 jr. als iAEer bij	Screening middels vergelijking en AI.	Ntb	Ntb	Ntb								Suggereer klasse E; neigt nogal gevoelig te zijn voor div. invloedsfactoren.	
J	Combinatie meting vochtgehalte (RH) en watersensor (DWP). Fusion 310 sensor.	Trisense	Batterij gedreven sensor (ca. 10 jr. levensduur) die meet via perforatie in de	4G/5G network met cloud solution Cirrusense	https://trisense.no/	Ja; Zone 0	TRL7 qualificatie test door Equinor verkregen.	Screening	Ntb	Ntb	Ntb							########	Potentieel klasse B; betreft tamelijk recht-toe-rechtaan techniek waarbij de combinatie de kans op false-calls sterk beperkt.	
		3-Sci																		
		Bartec																		
		Bernax	Water accumulation sensor																	
		C-Cube	ER/LPR																	
		ClampOn																		
		Corr Instruments LLC																		
		COSASCO	Fuse wire																	
		CUI Spotter	Fuse wire																	
		Eddyfi	PEC																	
		Eddyfi	Guided wave/UT																	
		E-Globaledge																		
		Ecorimor																		
		Ecuans	Thermography																	
		Hempel																		
		H2O Obvious	Water accumulation sensor																	
		Indusenz	Air humidity sensor																	
		Integrity Diagnostics																		
		iSensPro	Capacitive moisture measurement																	
		IRC Impect	X-Ray backscatter																	
		Kaefer Ilia																		
		Metal Samples Company																		
		Oceaneering/Acuren	Neutron/X-ray																	
		Oceaneering/Speir	Focussed Stress																	
		Haner Ltd	Concentration																	
		Permasens (Emerson)																		
		Percosens	Percolation sensor																	
		Previse																		
		REPCO CORROTEX	Pop-out fuse wire																	
		Resensys																		
		Rohrback Cosasco																		
		Senergetics	Optical fibre moisture measurement																	
		Sensuron																		
		Senemat Ltd.	EMAT Guided wave																	
		Structural Monitoring Systems Plc																		
		Sabbera Pi NDT	Sub-Terahertz sensing technology																	
		WaveScan																		
		Wi-Corr proximity	Radio wave antennas; Air humidity sensor																	
		Wisense (Draper; Yokogawa)	Array of low cost magnetic sensors																	

File / Tab: NewTechnologyRating.xlsx / NewTech

Print date: 8-3-2023

Rating based upon:

- ✓ True positives
- ✓ False positives
- ✓ False negatives

➔ Add-on to BP RB CUI management.

The framework for the developments:

Development along 5 main parts. These are:

1. Design and organization of the COI ecosystem ☑
2. Development and management of the digital COI platform (website) ☑
3. Internationalization of the COI platform ☑
4. Encouraging the use of the developed tooling; optimization ☑
5. Further development of existing and start-up of new practices ☑

Plan for 2024:

6. Incorporation of CUPS in the risk based CUI best practise ☐
7. Integration of Energy Efficiency measures (EED) with CUI management ☐
8. Validation as per proven practise of new monitoring techniques ☐

The tools; as a reminder:

General access: https://www.wcmvector.com/

Demo Beta tool: https://www.wcm-cuiassesment.com/

Live tool: https://wcm-cuiassessment.com (4 S's).

Beta tool, new role: Available for training purposes.

Appendix 7

Zerust ZIF tape Application and discussion

(Dale Matthews/Phil Low)

CUI IS A MAJOR ISSUE ON INDUSTRIAL PIPING AMOUNTING TO APPROXIMATELY 10% OF PLANT'S MAINTENANCE COSTS – DEVELOPMENT OF PREVENTIVE ACTIONS HAVE BEEN NEGLECTED

Corrosion Under Insulation (CUI)

Description & Challenge

- CUI is a severe form of localized, **external corrosion that mostly occurs on carbon,** low alloy steel and stainless-steel which are insulated
- CUI is most prevalent in the chemical/petrochemical, refining, offshore, and marine/maritime industries**. If left undetected**, CUI can result in **catastrophic leaks or explosions**, **equipment failure**, **prolonged downtime** due to repair or replacement, and **safety and environmental concerns**
- CUI accounting for an estimated **10% of a plant's overall maintenance costs** and **40%- 60% of its pipeline maintenance costs**
- **More than 90% of maintenance work** related to corrosion detection based on risk-based assessment shows no corrosion and, therefore, **could be avoided**

Customer Potentials

Reduction of "unnecessary" maintenance costs

Revenue lost due to **unplanned down time** (opportunity costs)

Mitigation of accident potential:
Direct accident costs & reputation costs

*The **global cost of corrosion** is estimated to be US$2.5 trillion, which is equivalent to **3.4% of the global Gross Domestic Product (2013)***

Source: NACE- national association of corrosion engineers, 2016; International Meaures of Provention, Application, and Economics of Corrosion Technology Study

PROTECTIVE TAPE WITH INHIBITOR AGAINST CUI

Zerust Inhibitor tape for CUI applications – technical partnership

- In QIII 2020 KAEFER UK asked CIE-SIS for technical evaluation of the ZIF tape, focussing on its potential use for easy field installation against CUI
- For the tape system a suitability test in accordance to ISO 19277 –Qualification testing and acceptance criteria for protective coating systems under insulation was initiated with an independent test institute
- CIE bundles technical competence for the KAEFER group and supports the introduction of innovative products, which are evaluated to the state of the technology, and in cooperation with CSM generates frame agreements with selected supplier on a global scale

	Technical advantages	Comments
Protection of insulated objects from CUI	> No complex blasting of the steel surface > No mixing of coating material and subsequent brush or spray application > Self-amalgamation of the tape through the long-established silicone matrix technology > Solid content inhibitor within the tape that is activated by the ingress of water > No consumption of the inhibitor as long as no water / no moisture is present > Inorganic formulation prevents ageing problems of the inhibitor > Transparency of the wrap allows easy inspection > Partnership with supplier ensures price advantages and joint marketing of innovative solutions	> High market attractiveness > Maintenance product > Simple application

Zerust® OIL & GAS
WORLDWIDE CORROSION SOLUTIONS

Zerust® Inhibitor Fusion (ZIF) Tape

Silicone Self Fusing Tape with Inhibitors

Corrosion Solutions

The Problem

- Unprotected flanges, valves and instruments can lead to crevice corrosion and frozen nuts and bolts.
- Crevice corrosion between flange faces is a severe problem where the wedging action of corrosion products can lead to a significant risk of product leakage.
- Frozen nuts and bolts can lead to hours of delay to cold cut all bolts.

The Solution
Zerust® Inhibitor Fusion (ZIF) Tape

ZIF Tape can provide corrosion protection for flanges, valves, instrument preventing the severity of these problems.

Product Description

- ZIF Tape is a corrosion inhibiting tape based on silicone elastomers with proprietary Zerust chemistry integrated into the matrix.
- It combines Zerust's proven corrosion protection benefits with the specific properties of a self-fusing film for easy, cold application.

Available in 36 ft. long, individual, whole rolls in 2", 4", 12" and 16" widths.

ZIF Tape Application
High Heat Temperature / Flange Protection

- ZIF Tape can be used as a protection for flanges against corrosion for temperatures up to 200° Celsius instead of the typically used Zerust® Transparent Flange Saver®.
- The Flange Saver is a transparent film infused with VCI that is wrapped around the flange, tightly secured, and forms an enclosure around the flange allowing the VCI molecules to adsorb onto metal surfaces to form a protective layer against corrosion.

ZIF Tape Application

Corrosion Under Insulation (CUI)

HISTORICAL DATA SHOWS THAT ABOUT 60% OF PIPE LEAKS ARE CAUSED BY CUI.

- CUI is any type of corrosion that occurs due to a moisture buildup on the external surface of insulated equipment.
- CUI is one of the (petro) chemical processing industries worst problems and the costs associated to mitigating it are astronomical.
- If undetected, the results of CUI can lead to the shutdown of a process unit or an entire facility, and in rare cases it may lead to a process safety incident.
- CUI is one of the most difficult processes to prevent.

ZIF Tape
Features

- It is stable under prolonged exposure to UV/sunlight and is translucent in appearance.
- It is non-tacky to the touch, but will 'fuse' within ~30 seconds to form a long lasting bond.
- It is elastic in nature and can be stretched to provide closer fits to surfaces to which it is applied.
- This close fit coupled with the application tension minimizes the gaps/spaces where moisture might penetrate.

Winner of the French Oil & Gas Council Innovation Award for Zerust's® ZIF Tape

ZIF Tape
Features

- Provide protection by Zerust Volatile Corrosion Inhibitor (VCI). YES
- High capacity to conforms / molds when wrapped around/onto complex shapes. YES
- Bond to itself rapidly and remains non-tacky to the touch. YES
- Cold, easy and quick application process. YES
- No residue remains, when remove the tape. YES
- Wind, sunlight UV, oxygen and seawater resistance. YES
- No heat/equipment required. YES
- Wide range of application temperatures YES
- Flame resistant when wrapped. YES
- Protection from welding sparks. YES
- Good mechanical and puncture resistance, even around sharp edges. YES
- At least 5-10 years of corrosion protection. YES

CUI Field Trial Introduction

- ZIF Tape being applied on petroleum refinery in Belgium, this included multiple areas of live trial on <+100deg.C lines.
- Client has historical issues of Corrosion Under Insulation (CUI) lines and looking for a more robust solution to provide longevity and maintain integrity for continued safe operations.
- Trial was conducted on various operational “live lines” from ambient to +100deg.C
- Trial timelines

- Implementation November 2018.
- Inspection of trialed areas October 2019.

CUI/Scab Repair Project Related Comparisons

Conventional Coating Vs. ZIF Tape

Conventional Coating

- 3 layer Epoxy
- Permittry
- Blast equipment/Hoses/ Gauntlets/PPE
- SA 2.5 – reliance on the skill of the application team
- BOLL cert
- Air purification tests
- Compressors (EX rated zone 0)
- Generators (EX rated zone 0)
- 3 x man team (min. requirement for blasting team)
- Paint
- Spray Equipment
- QA/QC Inspector
- Holiday test
- Potential mechanical damage to the coating allowing for corrosion triangle to take effect.

ZIF Tape:

- Minor Surface preparation; wire brush and solvent application.
- Only Cold Work Permit needed and 2 technicians for implementation
- Wrap ZIF Tape around pipe, making sure to overlap tape as you go to ensure adhesion.

Site 1 & Site 2 Locations

<u>Problem:</u>

Atmospheric widespread corrosion witnessed, client looking at reducing commercial factors and ease of implementation whilst maintaining integrity for continued operational without shutdown.

<u>Solution:</u>

Zerust Oil and Gas were selected to “trial” ZIF Tape on various scab repair areas, as client was keen to explore new technologies and smarter ways of working, client was able to conduct such trails with relative ease and non intrusive manner and no such need for blasting certifications and all the set up required for a 3 layer coating system.

ZIF Tape was applied on 2”-6” lines at multiple temperature(s) on approx. 1 metre trial sections.

Most trial sections were cleaned to ST2 and wrapped with ZIF Tape within a 10 minute period.

Site 1 & Site 2

Bare Substrate Exposed:

NDT – Non Destructive Testing

Thickness measurements were taken and writing on the steel substrate.

Site 1 & Site 2

50% Side By Side Overlap During Implementation

Protected vs Control

Scrapped back exposed metal left open to atmospheric corrosion vs protected pipeline using ZIF Tape.

Results and Conclusions
11 Month Field Trial with ZIF Tape for CUI

- The ZIF Tape was removed (October 2019) following a 11 month live field trial.
- The wrapped pipework/panels still had blank scraped surface, whereas the unprotected panels without tape had atmospheric surface corrosion.
- As witnessed in the provided images, the main pipelines were also protected from atmospheric corrosion.
- The trial was so conclusive and evidential that the client did not require to Re-NDT the protected areas as they showed zero signs of corrosion.

Trial Results

<u>Date(s):</u>

Conducted - November 2018

Inspected - October 2019

Duration - 11 months duration.

6 Month Field Trial for Pipe Protection

With Zerust® Inhibitor Fusion (ZIF) Tape

Trial Results

Protected Pipe and Coupon with Applied ZIF Tape

This pipe was jetty side in close proximity to a massive salt mountain creating a harsh and severe environment conducive for corrosion.

Removal of ZIF Tape 6 Months After Application with No Signs of Corrosion to Coupon

Zerust® OIL & GAS
WORLDWIDE CORROSION SOLUTIONS

Trial Results

Protected Pipe and Coupon with Applied ZIF Tape

This pipe was jetty side in close proximity to a massive salt mountain creating a harsh and severe environment conducive for corrosion.

Removal of ZIF Tape 6 Months After Application with No Signs of Corrosion to Coupon

Trial Results

Control Coupon

Protected Coupon After 6 Months

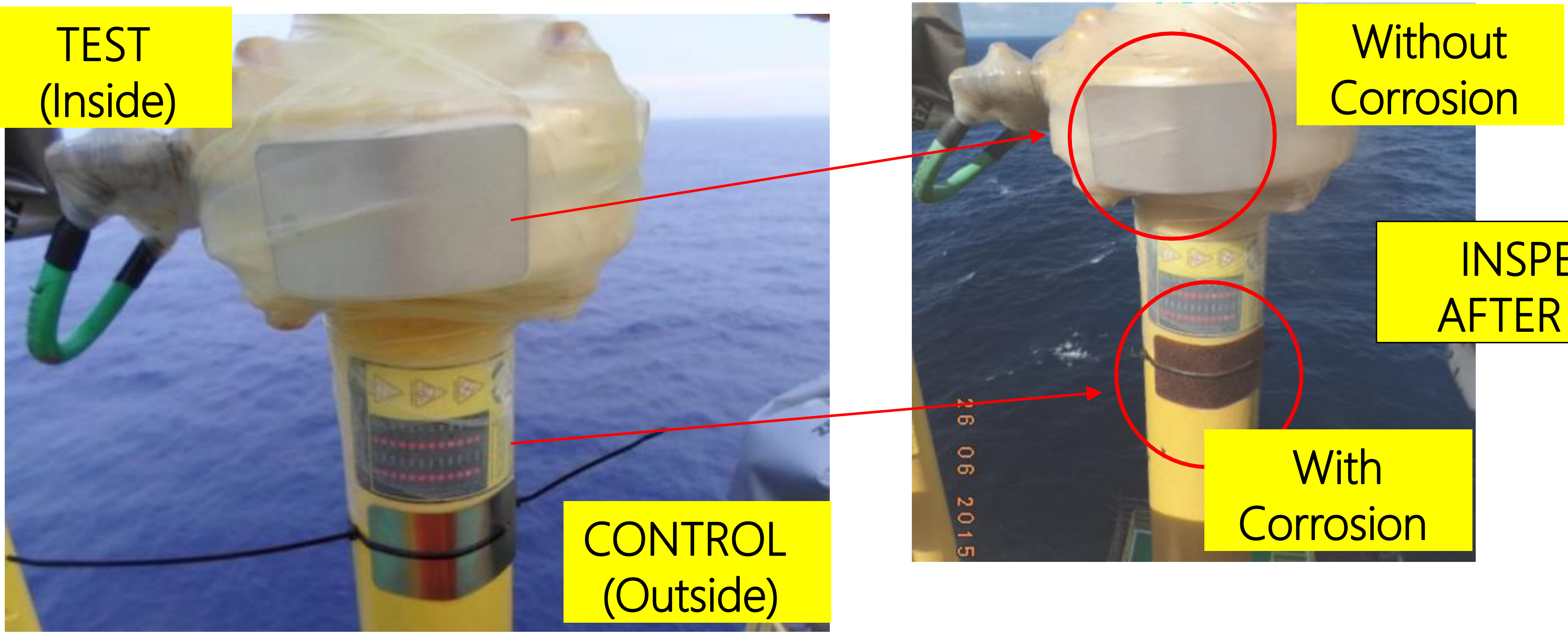
Application/Test Examples

Zerust® Inhibitor Fusion (ZIF) Tape

ZIF Tape

@Petrobras P56 FPSO – Offshore environment

Carbon Steel Panel SAE1010



INSPECTION
AFTER 63 DAYS

Zerust® Inhibitor Fusion (ZIF) Tape Flange Trials

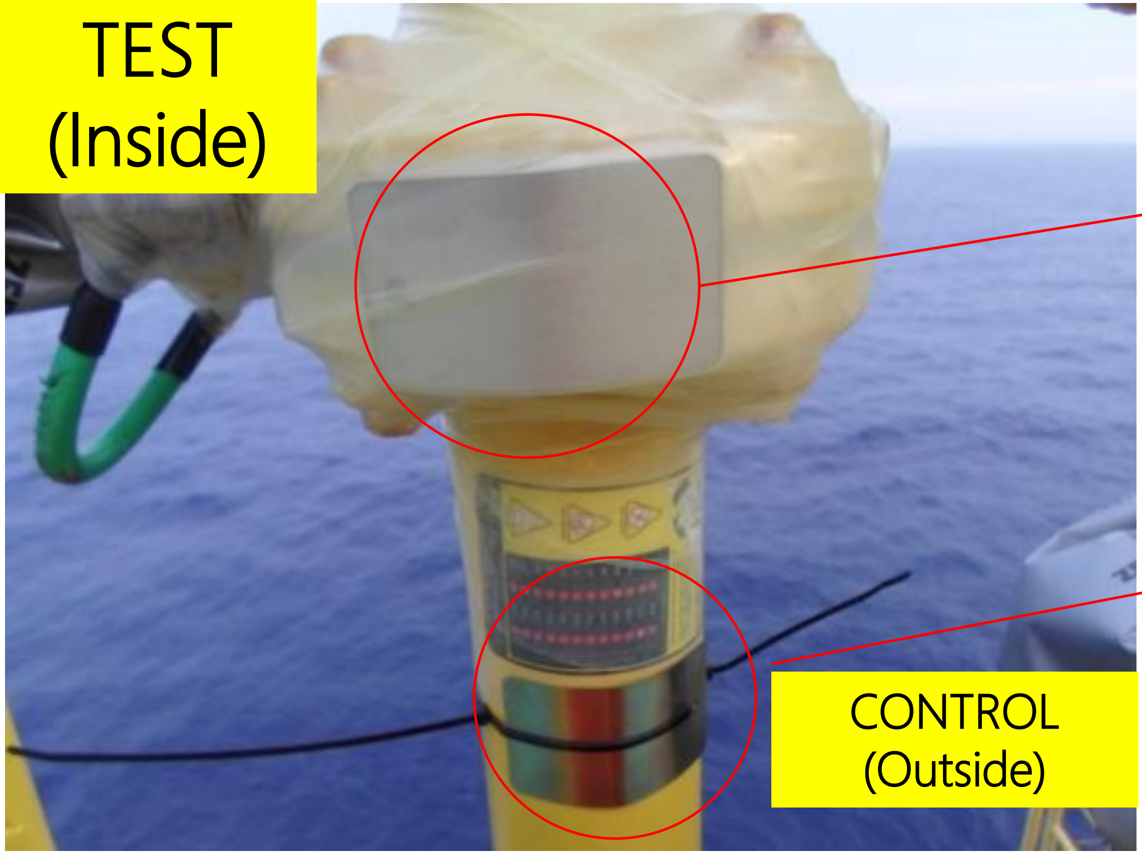
Petrobras FPSO P56

ZIF Tape Flange Trials

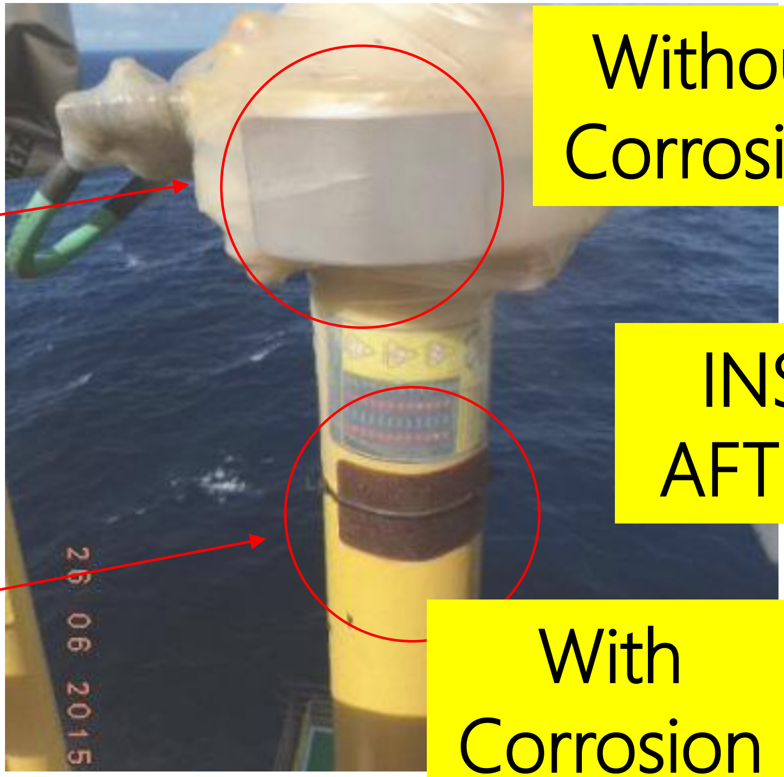
@Petrobras FPSO P56

Carbon Steel Panel SAE1010

TEST
(Inside)



CONTROL
(Outside)



Without
Corrosion

INSPECTION
AFTER 63 DAYS

With
Corrosion

ZIF Tape Application Procedure

1º Decontamination

Before using **ZIF Tape, Zerust® AxxaWash™ NW10-C** (5% into Fresh Water) needs to be applied onto the flange surface in order to provide powerful cleaning and corrosion prevention action on metallic and non-metallic substrates that are exposed to highly corrosive inorganic, bonded surface-reacted salts. This is an aqueous-based solution.

Inhibitor test, after 3 hours, using fresh water

WITH AxxaWash NW10	WITHOUT Inhibitor

ZIF Tape Application Procedure

2° Cold Application

Zerust® Inhibitor Fusion (ZIF) Tape Conclusion

- Easy to Implement
- Substantial overall commercial savings vs. conventional coating systems
- Non-Intrusive
- Continued In-Service Operational activities
- 5-10+ years of protection
- Ease to Inspect due to translucent nature of the ZIF Tape and ease if removal and/or reinstallation is required.
- Provides a 2 layer barrier:
  - By means of a physical barrier of a robust Silicone based material
  - By means of a corrosion inhibitor that will form a molecular layer of protection and neutralize any contaminants.

Questions

Gautam Ramdas
VP & Director
gramdas@ntic.com

Zerust® Inhibitor Fusion tape videos

Restricted Access Media Page Link

https://www.zerust-oilgas.com/restricted-access-media

Username: office@rig-techsolutions.com

Password: Rig-Tech1

Appendix 8

The leading Corrossion Under Insulation Partner for the process

(Peter Bosmans)

The leading Corrossion Under Insulation Partner for the process industry

sitech services

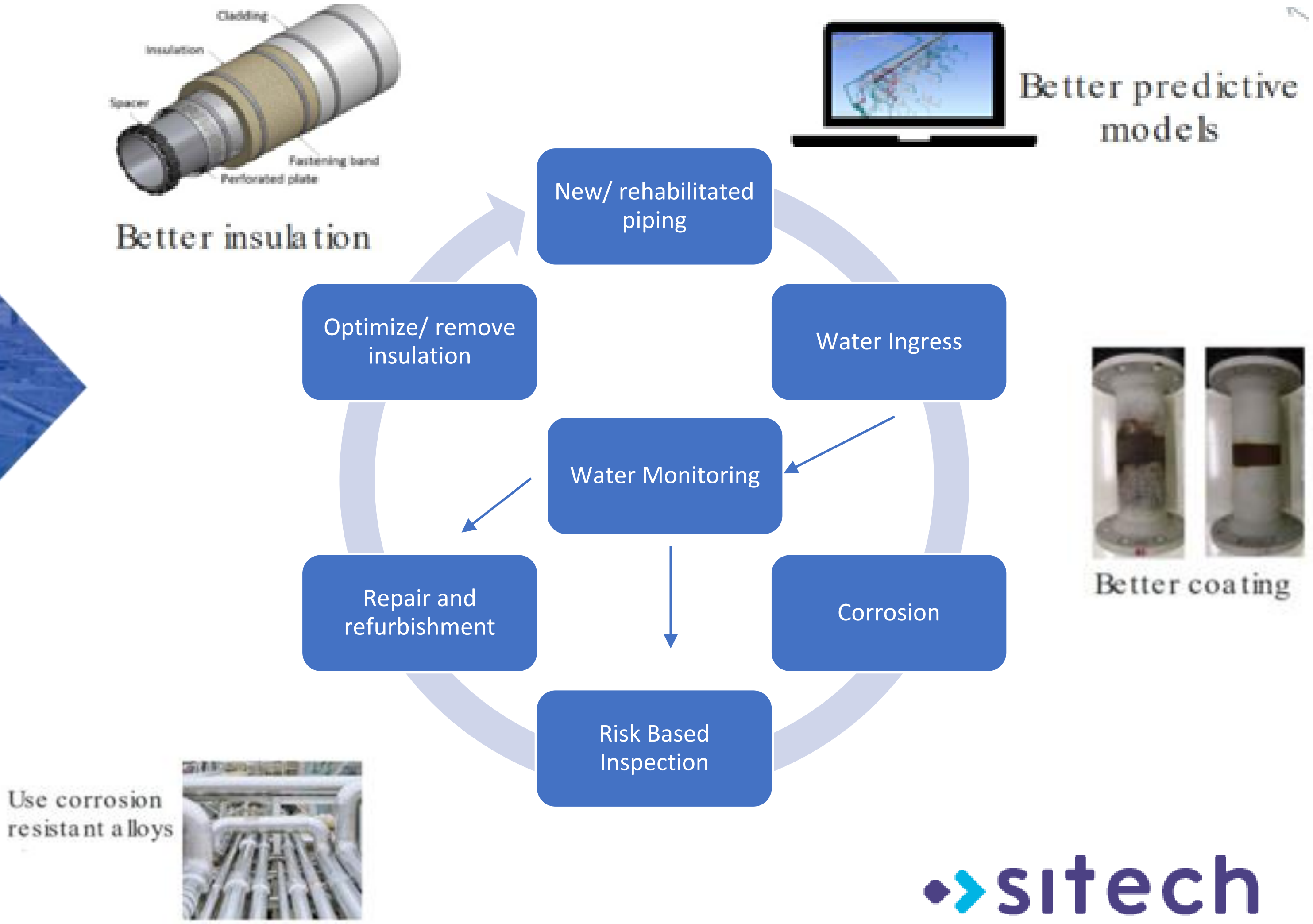
analyze. optimize. maximize.

CUI – a major corrosion problem

Colum dia 2 m, length 36 m
Repair costs 500 K€

sitech
services

The lifecycle of Corrosion under Insulation

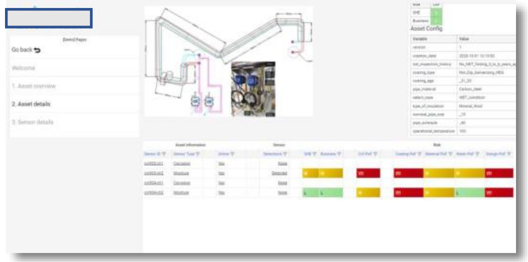


Source

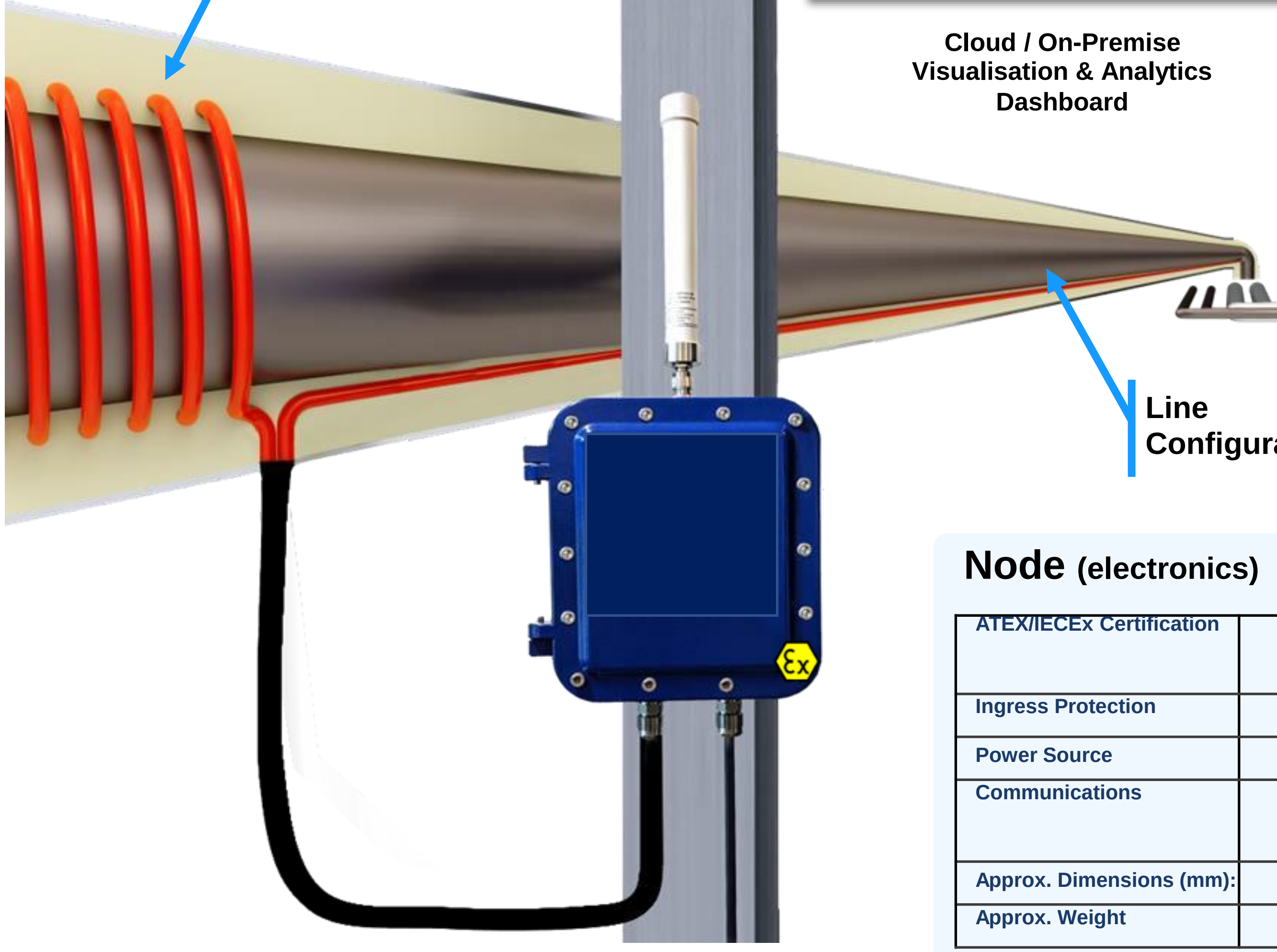
Equinor's CUI Management optimization by moisture monitoring under insulation, Minutes of EFC WP15 Corrosion in the Refinery Industry, 23 March 2021, page 27

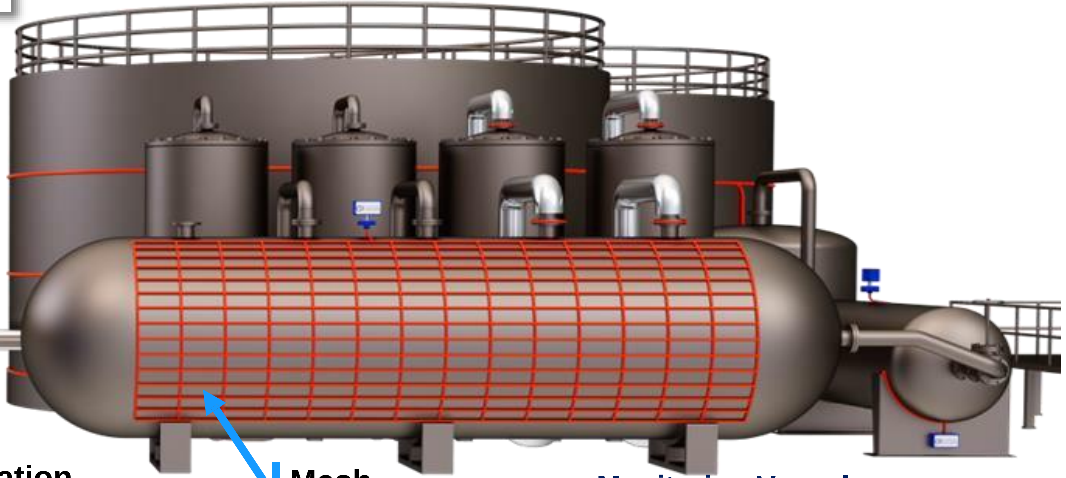
sitech services

CUI Risk Monitoring with Moisture and Corrosion Sensing



Cloud / On-Premise Visualisation & Analytics Dashboard





Monitoring Vessels

Unique benefits:

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

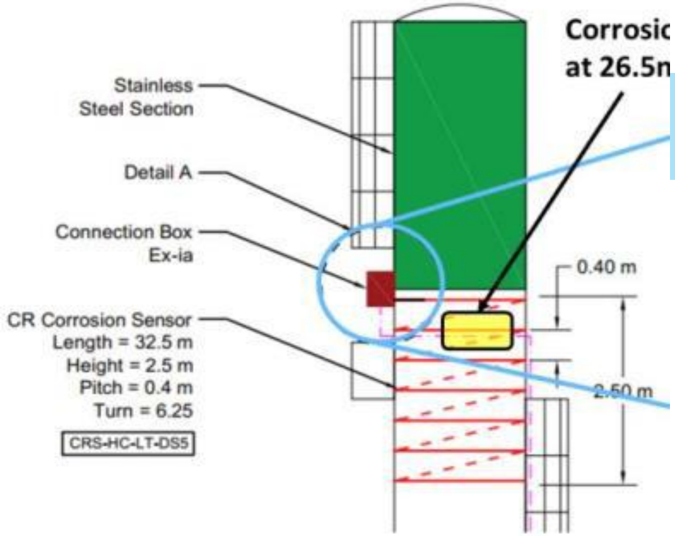
Node (electronics)

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
Communications	Wireless: WiFi/Cellular/WirelessHART/LoRa Other options: USB Data Logger
Approx. Dimensions (mm):	284H X 245W X 169D (Without Antenna)
Approx. Weight	11.2 Kg

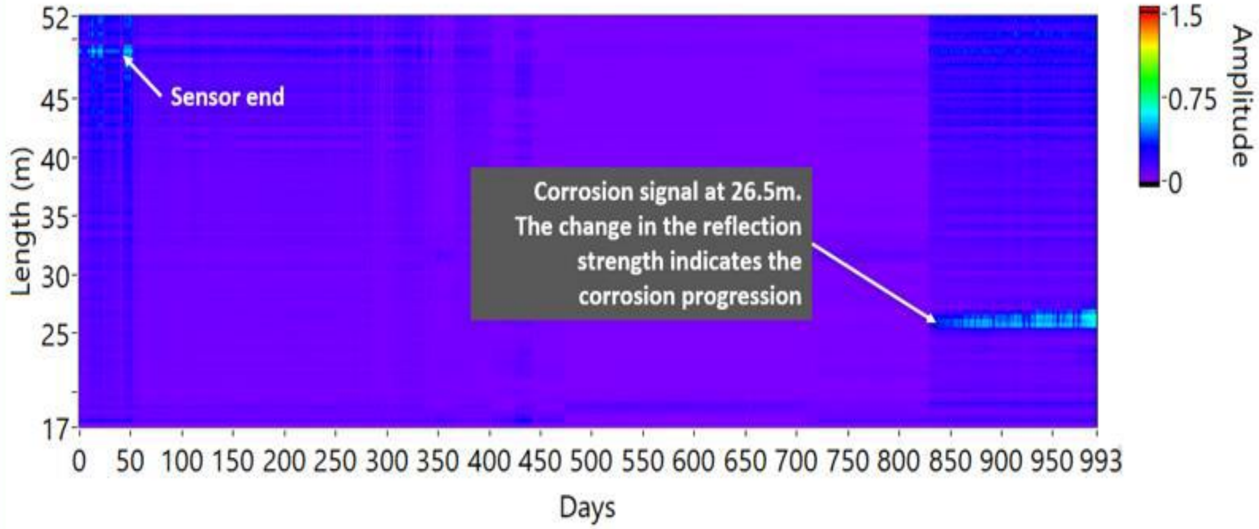
Sensors

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

User Case Corrosion Detection after 2.5 years

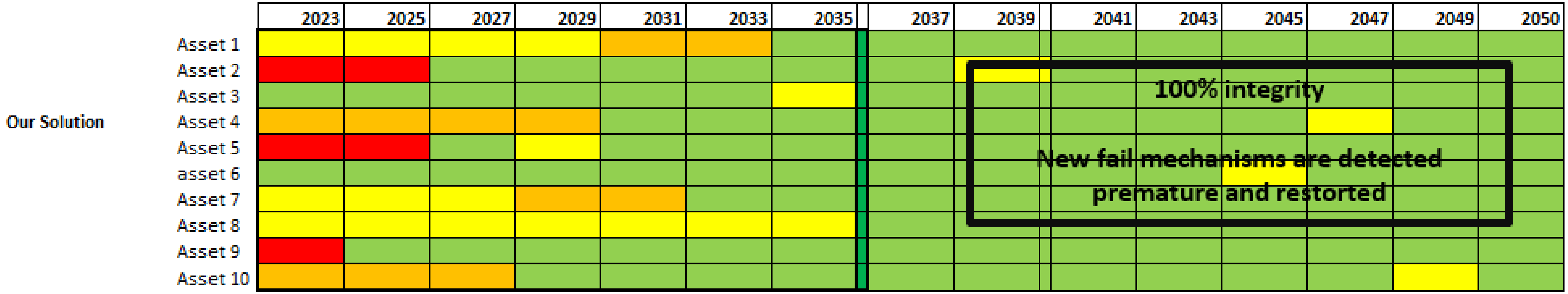


Corrosion Signal on the first support ring

Data Analysis Results	
Observations / remarks	An anomaly was observed at the 26.5m location (9m from the sensor start). This signal corresponds to the location marked on the asset drawing above — in the vicinity of a support ring on the column. The signal from the corrosion sensor has steadily strengthened through the Q11 reporting period. Hence, it shows characteristics of corrosion activity. It is recommended that an external inspection of the area be conducted to look for areas where water may penetrate the asset cladding and accumulate around the support ring.

Most common practise of CUI detection.

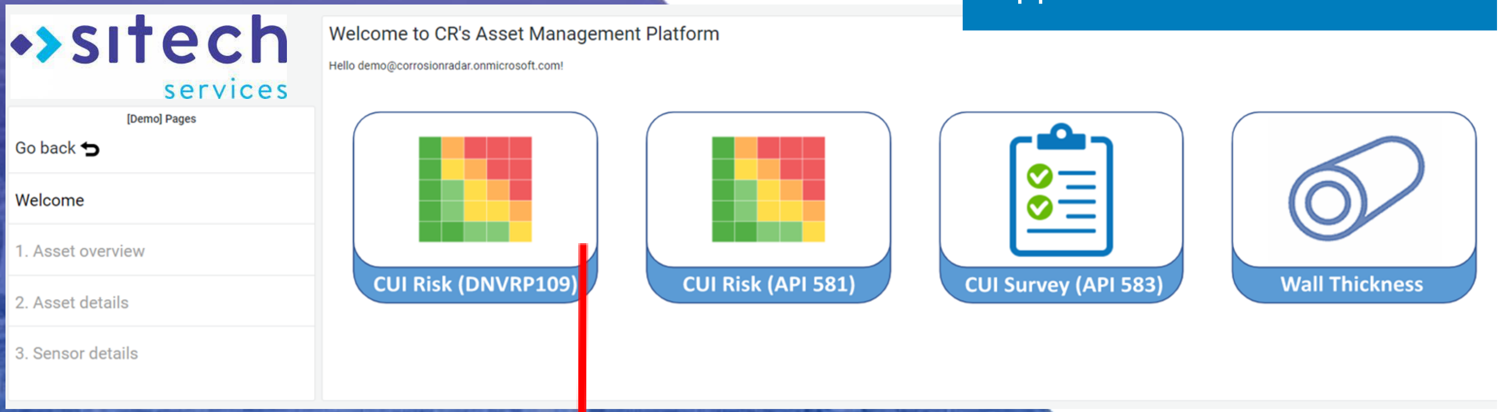
New practise of CUI detection.



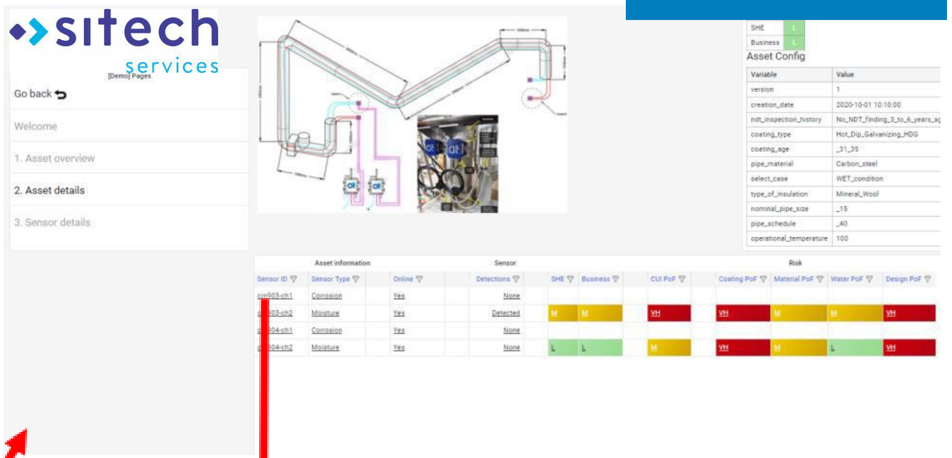
CUI Dashboard - Risk Analytics for inspection optimisation

Customised to Customer's Risk Matrix

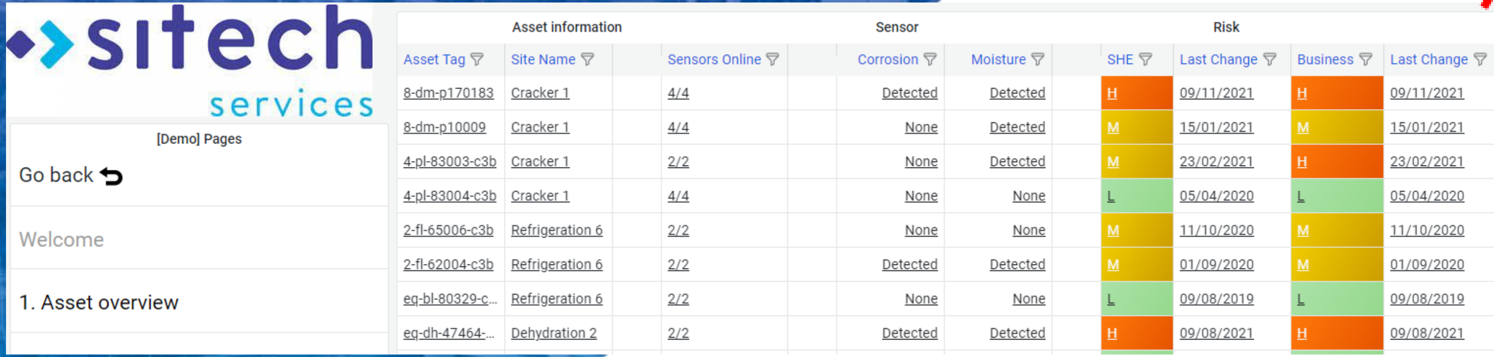
Applications



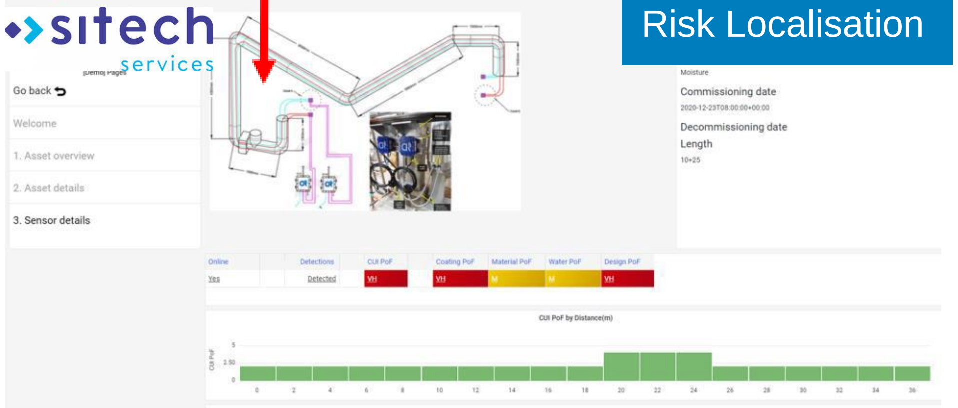
Asset risk (live)



Site wide risk snapshot (live)



Risk Localisation



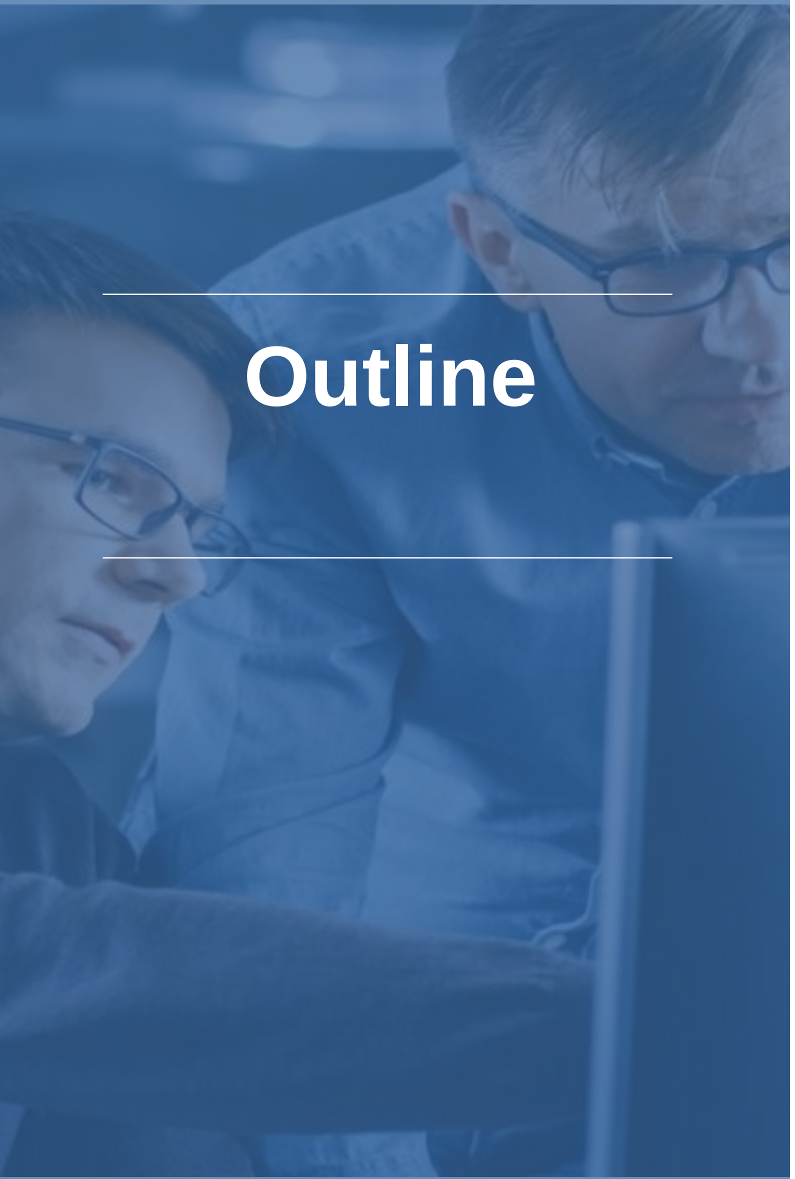
Appendix 9

High Temperature Hydrogen Attack Joint Industry Project

(Gerrit Buchheim)

High Temperature Hydrogen Attack Joint Industry Project

Dave Dewees, Sridhar Srinivasan, Gerrit Buchheim, Brian Olson



Outline

- Becht HTHA Joint Industry Project
- JIP Benefits / Program Objectives
- The Model
- Program Tasks and Deliverables
- Schedule / Summary
- Path Forward and Next Steps

HTHA JIP Principals

JIP Manager

Sridhar Srinivasan

- **Program Leader (Ex)** – Multiple Honeywell Joint Industry Projects (JIP) related to corrosion in refinery applications over the last 20 years
- **Member – Board of Directors** (2016-2019)– AFPM (*American Fuel and Petrochemical Manufacturers*)
- **Chairman** (2016-2020)– STG62 (NACE committee on Corrosion Monitoring)

25+ years of industry experience leading JIPs and development of corrosion / engineering prediction models

Principal Investigator

Dave Dewees

- **Instructor / Developer** – ASME Master class for elevated temperature materials/design
- **Lead Investigator / Author** – API 579-1/ASME FFS-1 Materials Properties Council (MPC) JIP on Fitness for Service, Weld Residual Stress
- **Inaugural Chair** – ASME special working group on high temperature technology

Creator of current Becht HTHA model with 20+ years of industry experience

Principal SME

Gerrit Buchheim

- **HTHA Industry SME** – A leading industry Metallurgical SME on HTHA, Sulfidation, Wet H_2S Cracking and Amine Cracking, and Refining Corrosion Mechanisms. Member of API 941 HTHA for over 25 Years
- **Charter Member** – API 579/ ASME FFS-1 committee on FFS
- **API Task Group Leader** – First chairman of API 571 Damage Mechanisms task group, Vice Chair API 970 on CCD's, API 945 Amine SCC chair and the original author of API 939-C (Sulfidation), Vice Chair. NACE SP02-96 Wet H_2S Cracking

40+ years of industry experience as HTHA SME and legal expert

HTHA SME

Brian Olson

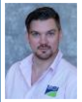
- **HTHA Industry SME** – A leading industry Metallurgical SME on HTHA with extensive and proven experience in leveraging advanced technology to practically impact asset integrity management

  He has previously developed HTHA damage models for carbon, C-0.5Mo, and low alloy steel materials to support HTHA specific RBI and FFS assessments
- **Lead Investigator** – former lead investigator for a major JIP on HTHA

25+ years of industry experience as a high temperature and HTHA SME

HTHA JIP Principals

Software Dev. Lead



Mark Fronek

- Responsible for HTHA JIP Model and all software development, testing and support activities
- Demonstrated expertise in working with product owners, technical SME's and software development specialists to create powerful and user-friendly web-based software for engineering applications

20+ years of engineering software development and technical support experience

Principal NDE SME

Mark Carte

- Will oversee the HTHA NDE aspect of the JIP and has demonstrated expertise in the practical detection of HTHA damage
- expert in the latest NDE technology and specializes in developing multidisciplinary NDE approaches focused on integration with FFS

40+ years industry experience with active leadership roles in in API Inspection and Mechanical Integrity Summit and Sub-Committee on Inspection and Mechanical Integrity

Advisor NDE

Dr. Mark Lozev

- **HTHA Industry SME** – A leading industry NDE SME on HTHA and Refining Corrosion Mechanisms with extensive materials and FFS experience.
- **Leader** in HTHA NDE technology developments and implementations. Received ASNT 2021 Paper Award "FMC/TFM and PAUT for HTHA Inspection".

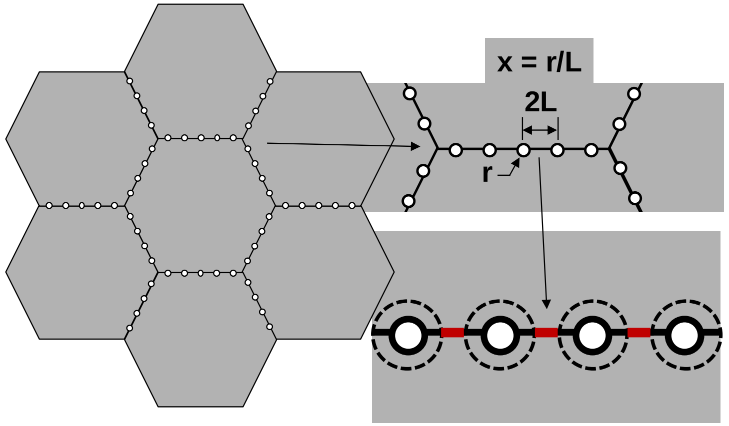
45+ years industry, research and academia experience with leadership roles in API HTHA activities - Vice-Char of API 941 HTHA NDE Task group (2016-2020), Technical Editor of API 586, Section 2 "Inspection for HTHA" (2021-current).

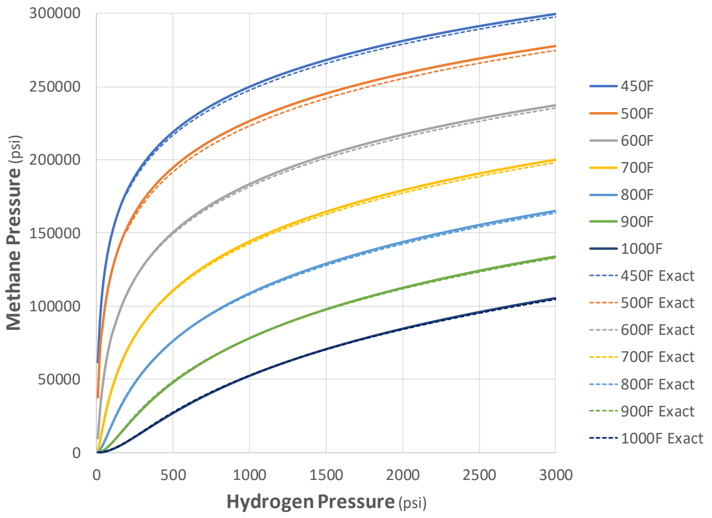
JIP Sponsorship Details

- Multi-year program
  - 3 Year program designed for data and model development
  - Program start date of Feb 1, 2022
- Program currently has <u>six</u> signed sponsors
- Program designed for sponsorship of 8 companies at full scope

JIP Objectives

- Create data and augment existing Becht HTHA model to calculate remaining lives for components in high temperature hydrogen service
    - Directly consider carbon steel, C-0.5Mo and low alloy steel base metal, HAZ and welds
    - Use critical factors to reduce observed data scatter
    - Generate capability for through-wall damage modeling, facilitating direct linkage between damage, inspection and metallurgical sampling / analyses
    - Deliver a comprehensive HTHA characterization / quantification model and life prediction software
- Use data and model for safe deferral versus replacement decision-making for critical equipment





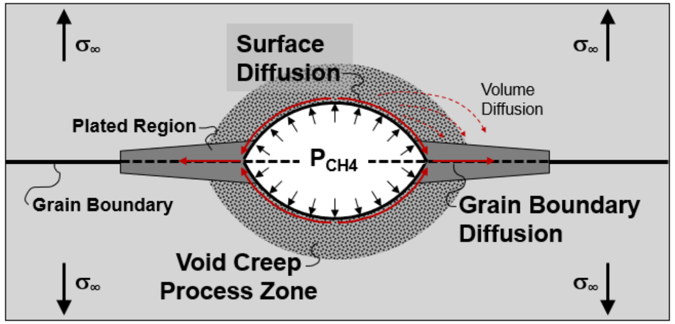
JIP Objectives / Benefits

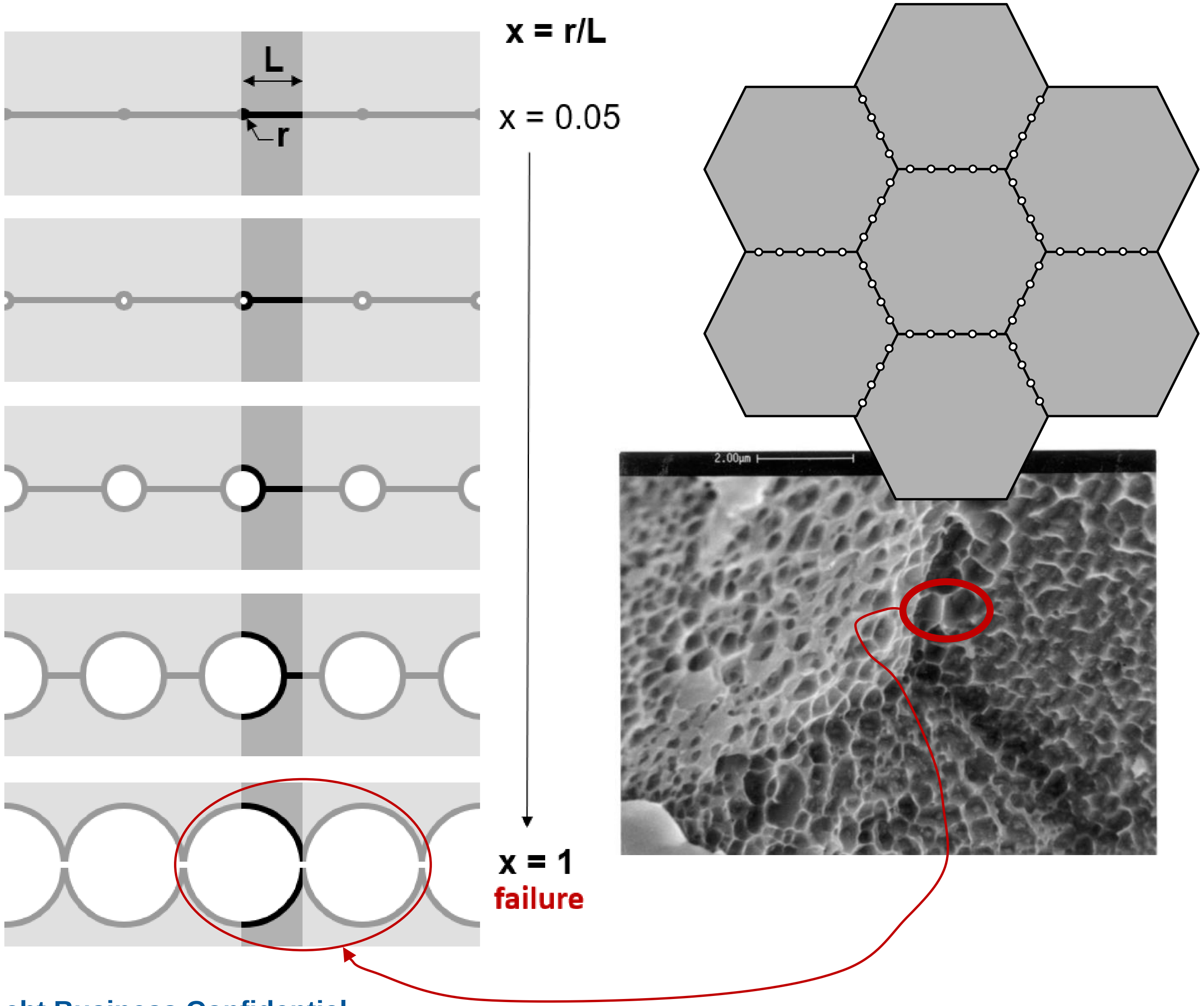
- Establish concrete inspection procedures based on life-cycle stage specifically targeted to avoid overly sensitive (false positives) characterization
- Correlate model with inspection data to support accurate life predictions and FFS assessment
- Help sponsors rapidly transfer existing data on their equipment into the new framework

Current Industry	Becht HTHA JIP
Assess equipment with a "go/no-go" or "damage/no-damage" approach	Assess equipment based on critical factors for damage levels from surface initiation to final failure
	Rapidly provide data- and statistically-derived remaining lives for a variety of future operating scenarios
	Assess equipment considering through-wall driving force and corresponding damage propagation rate (progressive damage front vs. likely arrest)
Perform inspections capable of detecting isolated voiding often leading to false or uncertain calls	Perform inspection with sensitivity prescribed to reliably find damage just capable of affecting mechanical integrity
Retire equipment that may or may not have true HTHA damage due to uncertainty in findings and lack of life assessment capability	Assign maximum model damage based on inspection-driven data and base retirement decisions on quantified through-wall damage rate and safe remaining life
Apply imprecise definitions of HTHA damage extent (i.e. Stage 1, 2 and 3 . . .) that do not have a direct tie to remaining life or FFS	Apply a consistent, logical, well-defined and demonstratable degree of damage that can be referenced to each of the critical factors influencing FFS and inspection NDT detection limits/strategy.

Becht Approach - Void Growth Modeling

- We've based our approach on the most sophisticated and well-developed HTHA model (40+ years of international development)
- Allows calibration to both type and extent of damage
- Result is something that truly makes sense relative to experience
- Not a black-box – overwhelmingly publicly available

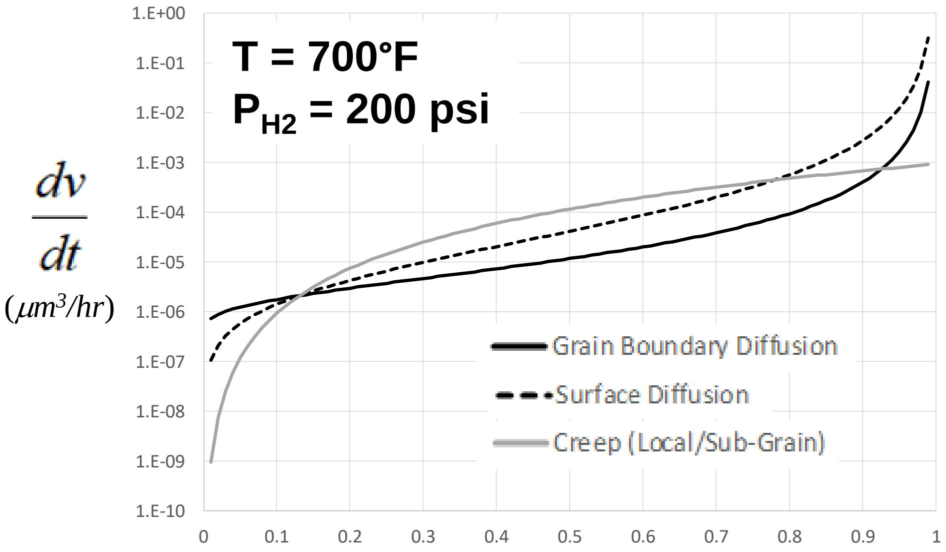


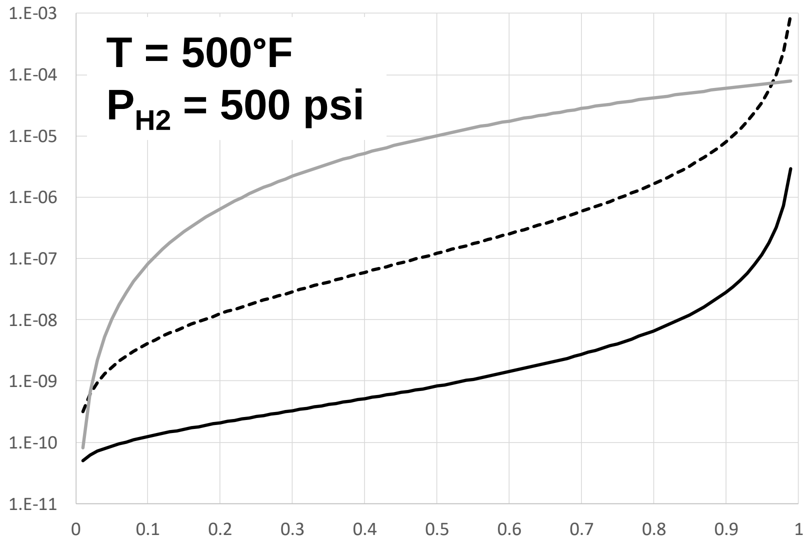


Why a Void Growth Model? (1)

- Multiple mechanisms gives ability to fit complex behavior
- Equations look complex but essentially all variables are known, physical constants
- Really just a simple combination of 3 power laws

$$\frac{dv}{dt} = 2\pi \frac{(D_b\delta_b)_o \exp\left(-\frac{Q_b}{R_g\cdot T_{abs}}\right)\Omega}{k\cdot T_{abs}} \frac{1-x^2}{x^2\left(1-\frac{x^2}{4}\right)-\frac{3}{4}-\ln(x)}\left(P_{CH_4}\right) + 2\pi(x\cdot L)^3 \frac{(D_v)_o\exp\left(-\frac{Q_v}{R_g\cdot T_{abs}}\right)A\cdot b\cdot\mu}{k\cdot T_{abs}}\left(\frac{3}{2n}\frac{P_{CH_4}}{\mu}\right)^n$$





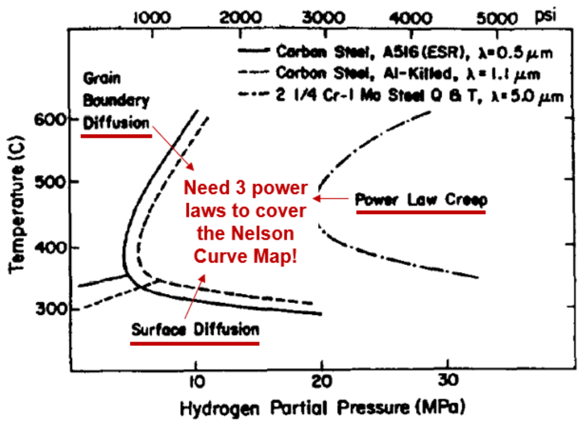


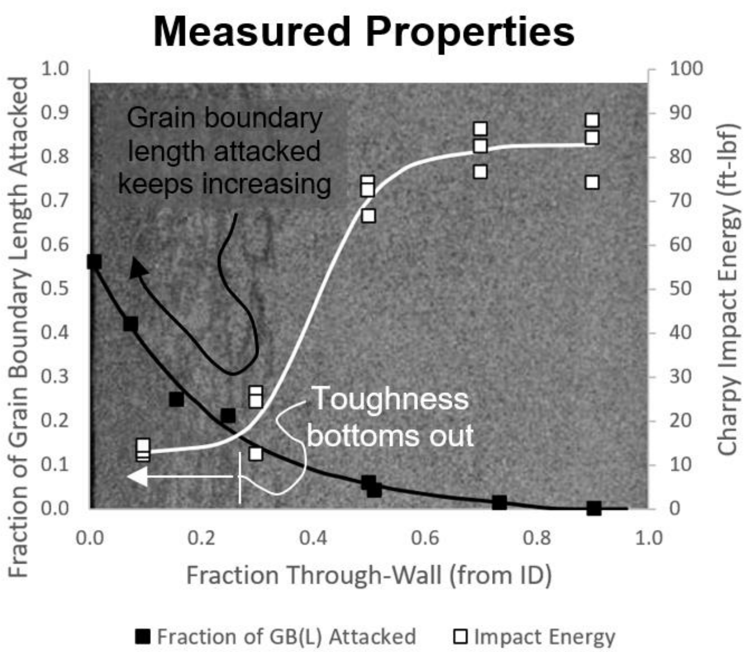
Fig. 6. A bubble growth mechanism map showing mechanism transition curves for two carbon steels (A516 and Al-killed) and a $2\frac{1}{4}$Cr–1Mo Q&T steel.

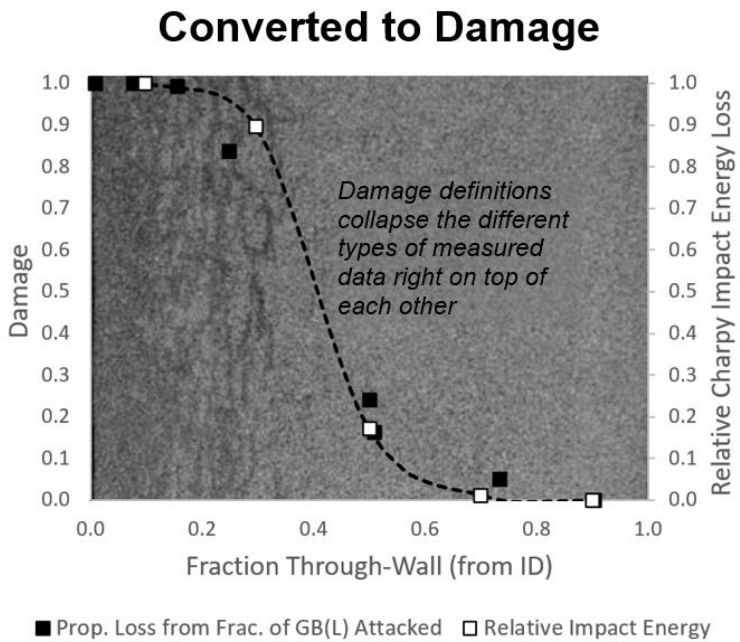
Why a Void Growth Model? (2)

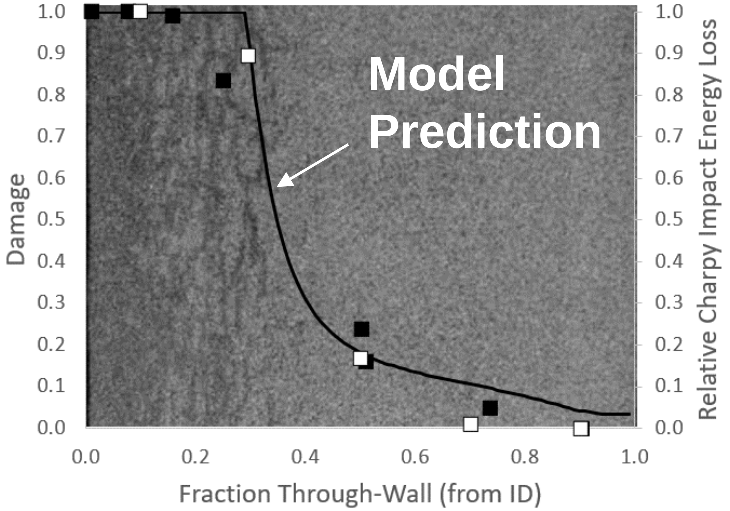
- Beyond flexibility to fit a range of observed behaviors, it turns out the model damage can be directly related to both voiding and property loss:
- What that means is we have a real and direct tie between the model and inspection (physical damage) AND FFS (property loss)

Damage Based on Grain Boundary Length Attacked: $D_{FL} = \min\left(\frac{FL}{FL_{crit}}, 1\right), \quad FL_{crit} = 0.25\ (25\%)$

Damage Based on Property Loss: $D_{C_V} = \frac{C_{V,high} - C_V}{C_{V,high} - C_{V,low}}$

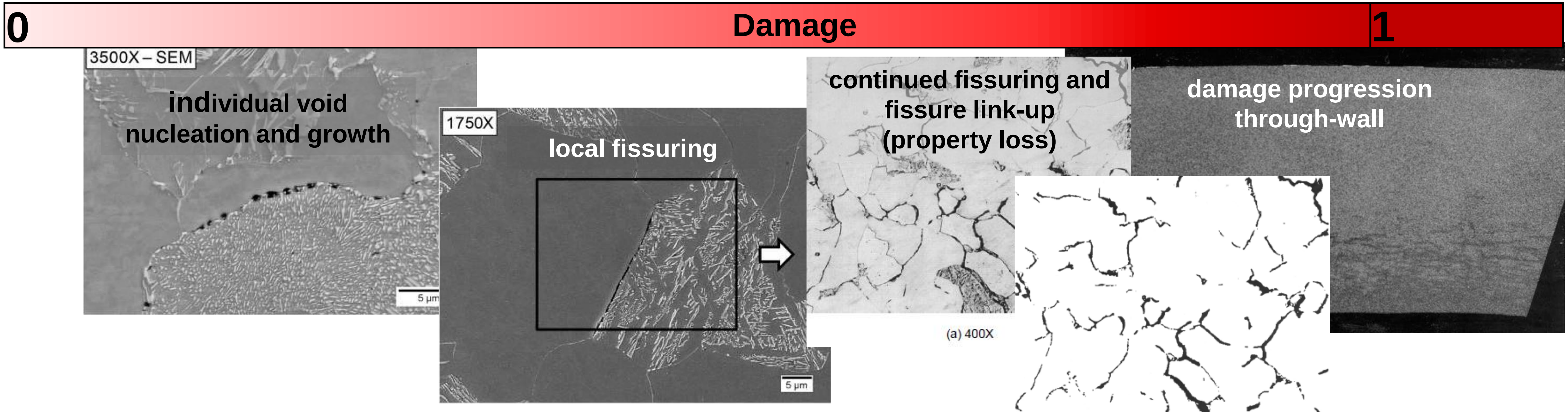






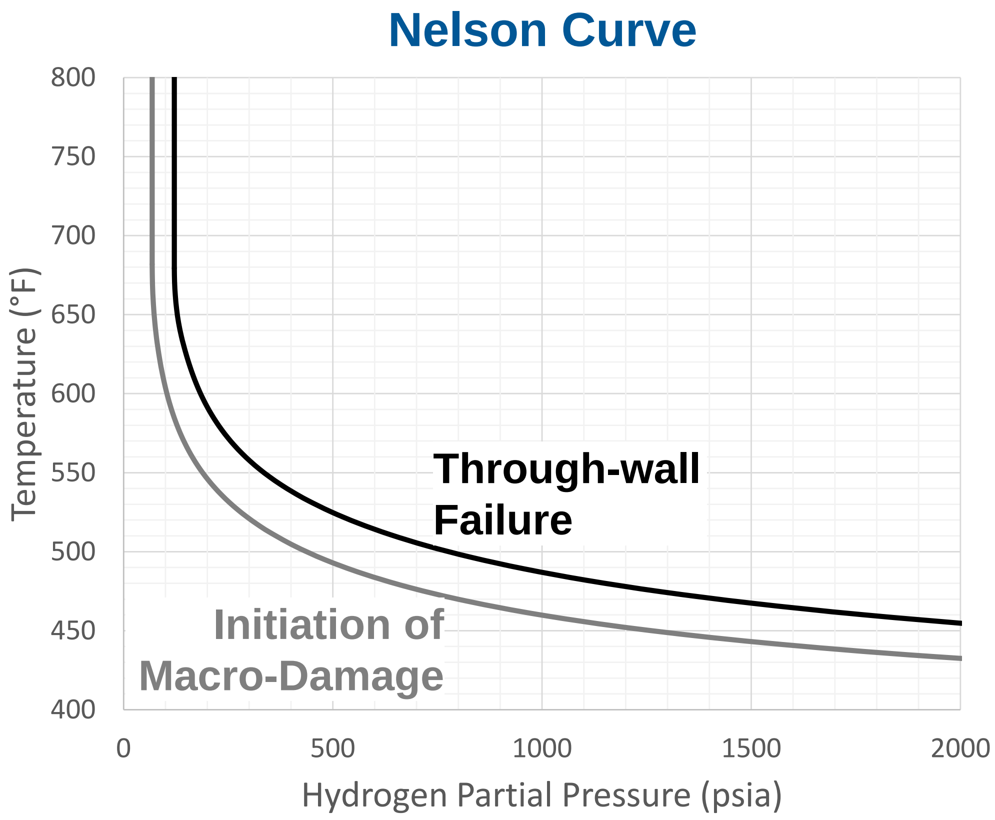
Why a Void Growth Model? (3)

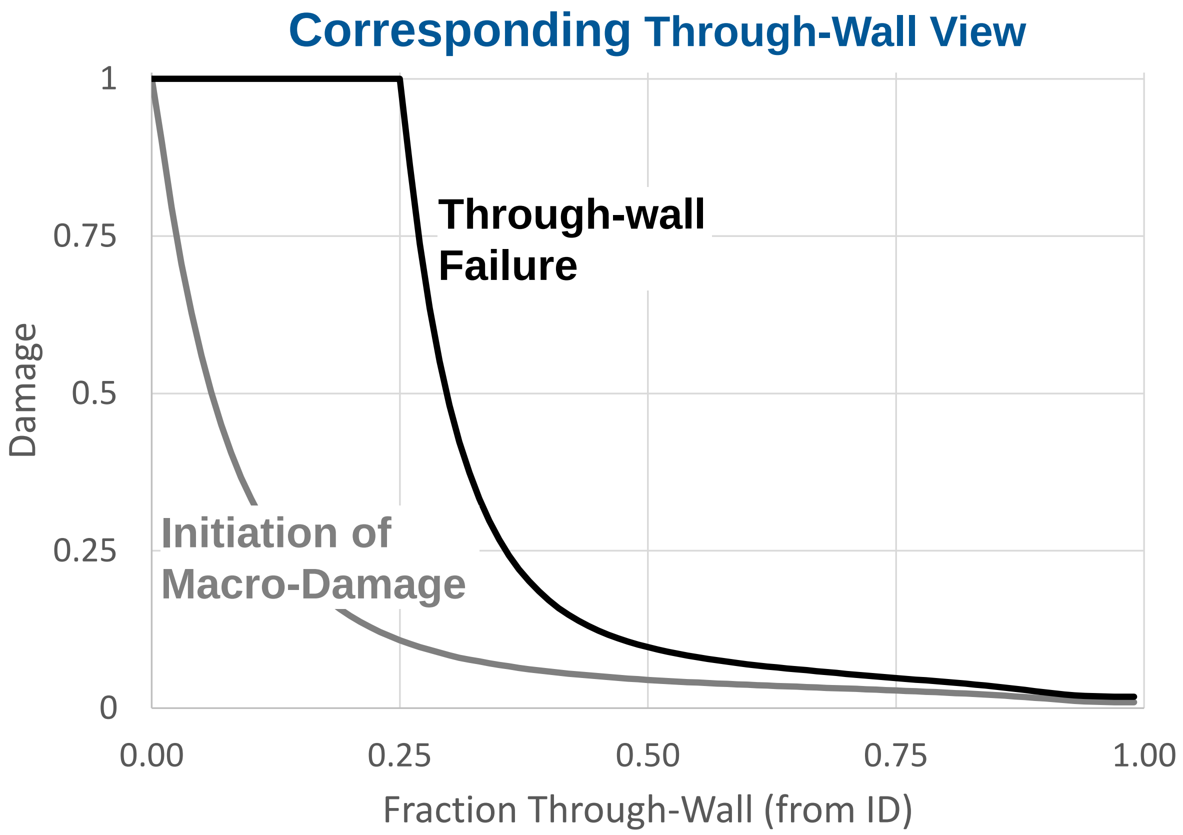
- Our JIP is about maximizing this tie to the greatest extent possible
- This is much more than a screening tool – it is a full-fledged and predictive damage mechanics model that can be used for FFS



How Are We Unique? (1)

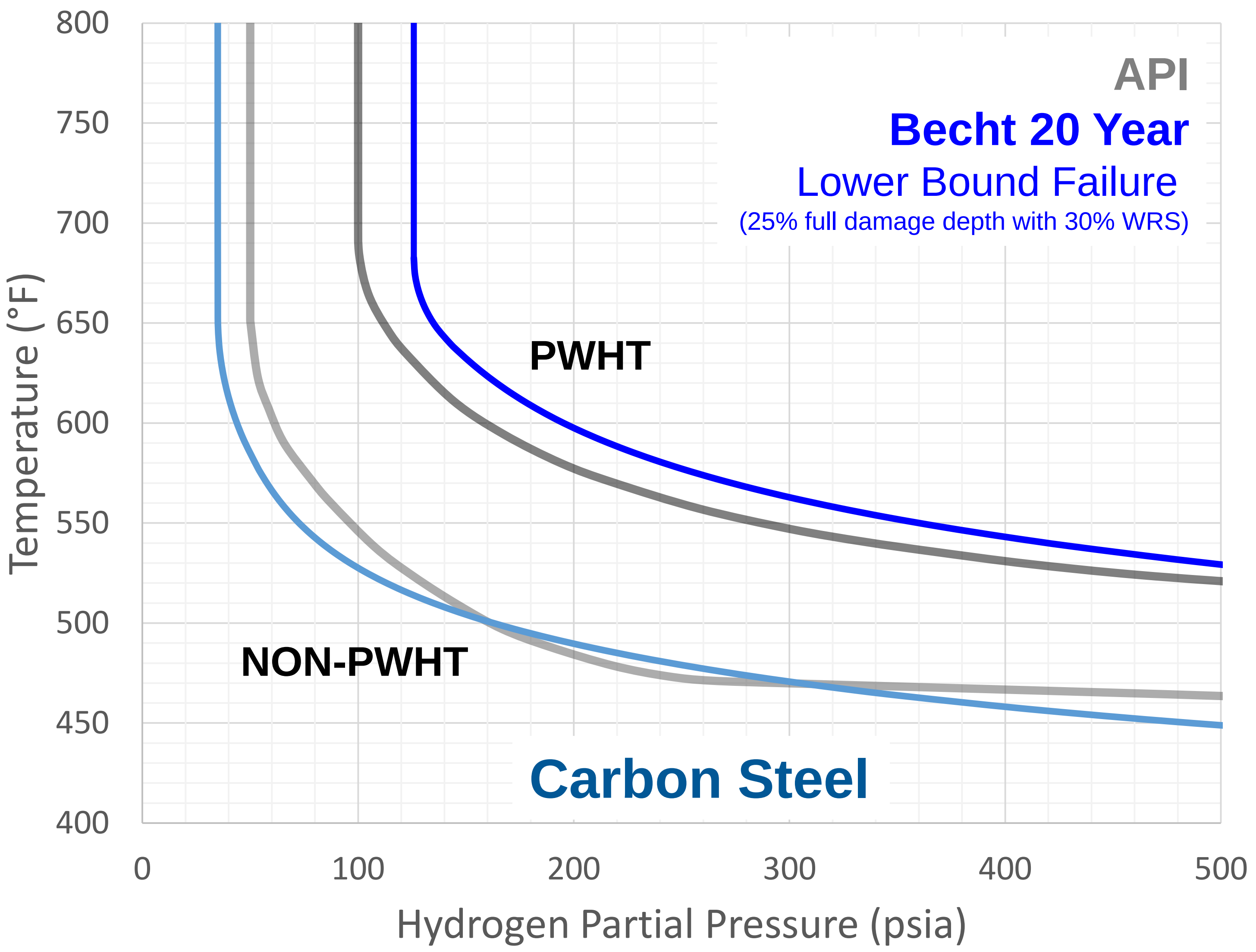
- The well-established void growth model gives a clear definition of “damage”, so we know exactly what a Nelson Curve means
- 200,000 hour Nelson Curve for PWHT carbon steel shown below to illustrate





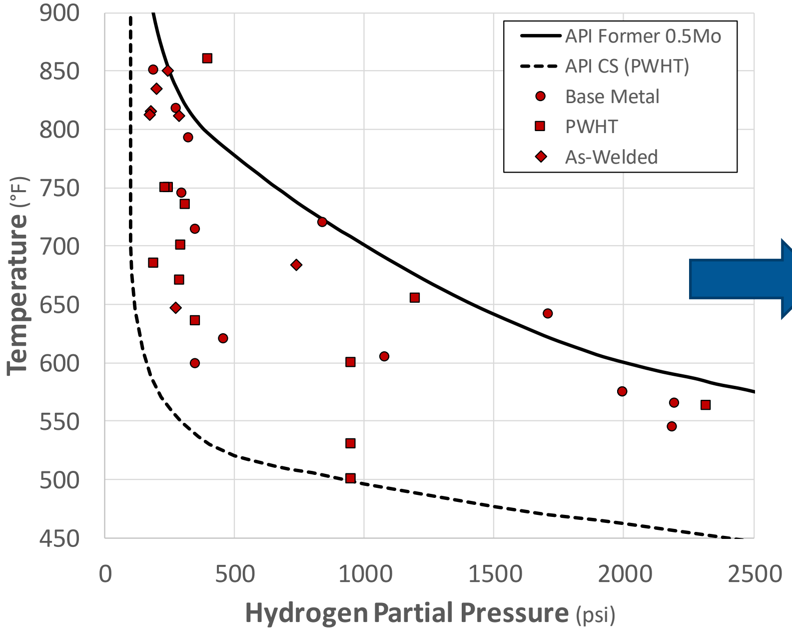
How Are We Unique? (2)

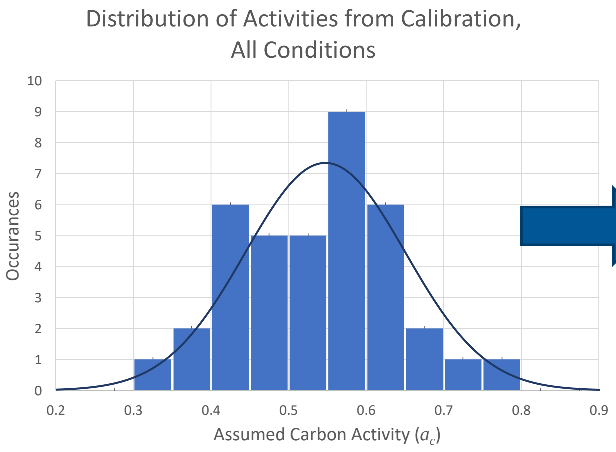
- And extremely importantly, the Nelson Curves the model predicts closely reproduce the API Nelson Curves and the decades of experience embedded in them
- Any reasonable model must do this – not just shape, but also duration

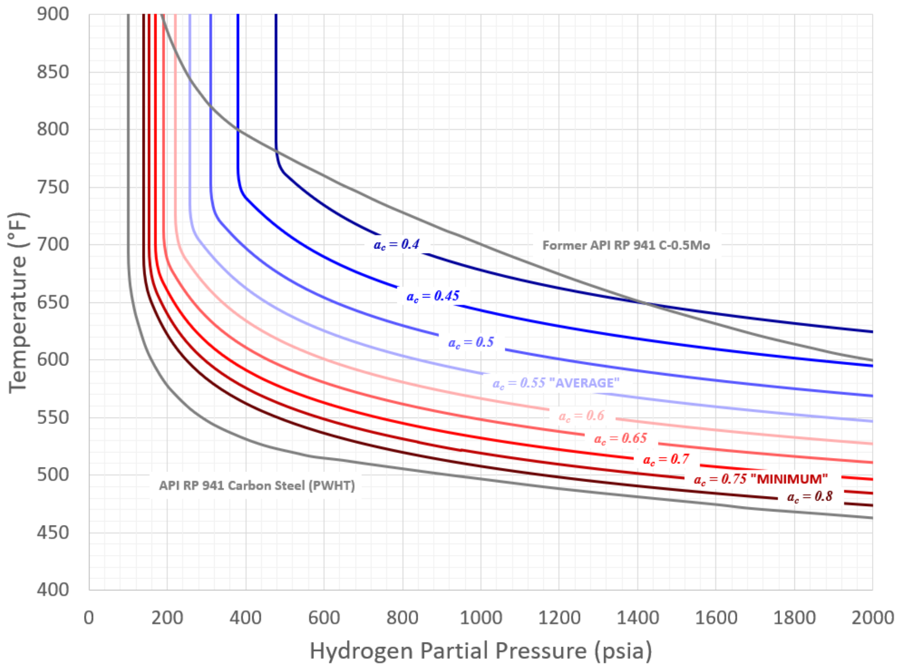


How Are We Unique? (4)

- And it's not just carbon steel - major differentiator with our method is treatment and predictiveness for C-0.5Mo
- In the Becht model C-0.5Mo variability is characterized by the carbon activity, a_c
- This is a physically meaningful quantity – it varies with real factors like Mo/C ratio, etc.
- Results fit right in the expected Nelson Curve window, and allow statistical description of possible performance







JIP Tasks and Deliverables

Tasks

Task 1: Introduction of Becht HTHA Model to Sponsors → Task 2: Material Testing → Task 3: Model Extension → Task 4: Correlation with Inspection and FFS → Task 5: Software Model Delivery

Deliverables

Program Data

JIP Final Report

HTHA Modeling Software

Contact Me

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- gbuchheim@becht.com
- +1-808-264-5874

Appendix 10

RBI plan for Steam Generation Boilers

(Focusing on Damage Mechanisms & Preventive IOW)

(Askar Soltani)

RBI plan for Steam Generation Boilers

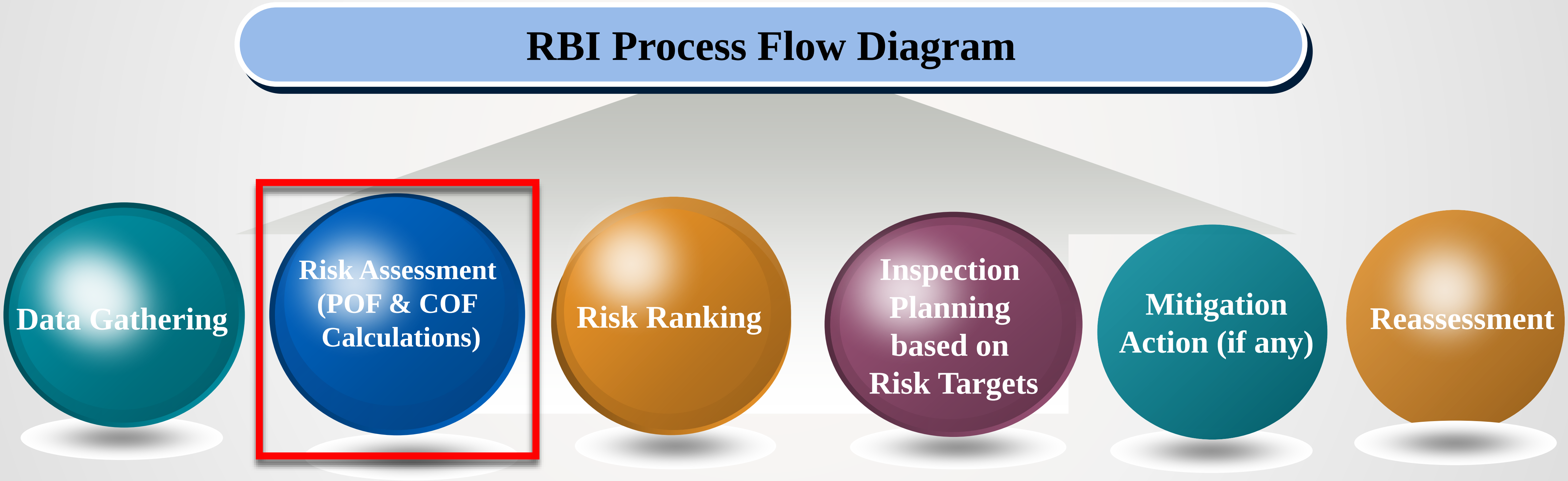
(Focusing on Damage Mechanisms & Preventive IOW)

Presented By: Askar Soltani

South Pars Gas Complex, IRAN

Inspection Methods in Oil & Gas Refineries can be categorized as following:

- Conventional Periodic Inspections (Such as annual inspections during overhaul period or after failure occurrence
- Inspections based on Risk Assessment (An effective methodology which is based on the failure history of the equipment or component and is planned by risk assessment and definition of proactive inspection methods and inspection interval)



In this presentation I am going to focus on step 2 of RPI implementation which is “Risk Assessment” by calculation of POF and COF. For POF measurement we need to be familiar with all damage mechanisms in steam generation boilers and determine dead legs and most probable components which are vulnerable to corrosion.

POF & Damage Factor

In standard API 581, the following formula has been proposed to calculate POF (Probability Of Failure):

$$P_f(t) = gff \cdot F_{MS} \cdot D_f(t)$$

gff stands for generic failure frequency and F_{MS} is the management system factor and D_f is damage factor. So, it is obvious that the calculation of POF as one of the main steps of the risk analysis in RBI methodology is to know and calculate damage factors in boiler systems. In this way, we need to know potential damage mechanisms in boiler units.

Common Damage Mechanisms in Boiler Systems are as following:

- Oxygen Corrosion
- Overheating (Short Term & Long Term)
- Fire-Side Corrosion
- Dew-Point Corrosion
- Low pH Corrosion
- Caustic Corrosion
- Under Deposit Corrosion

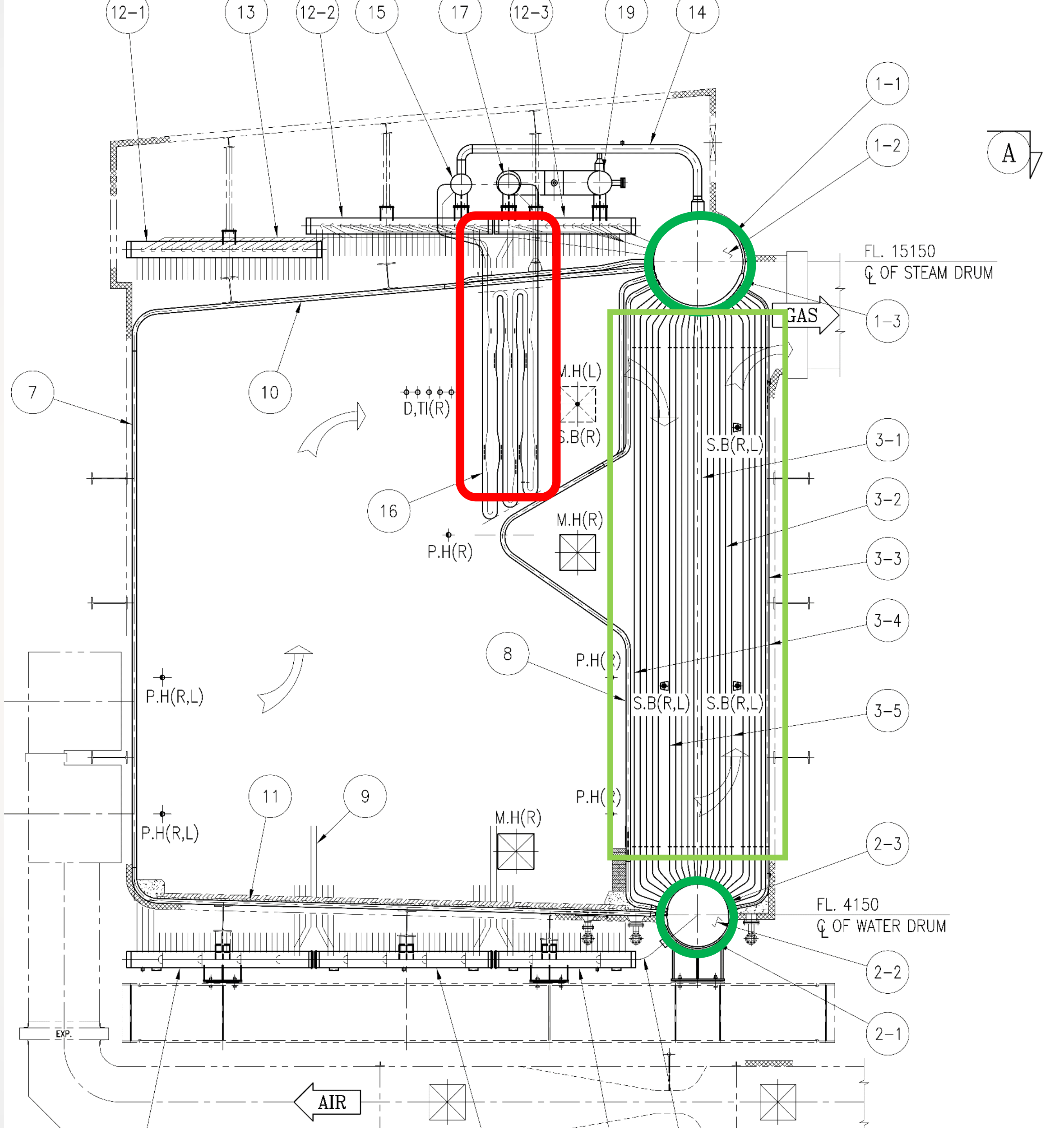
Based on field experience, Localized Thinning is always observed under the deposits which could be related to following damage machanisms:

- Caustic Gouging
- Acid-Phosphate attack

Schmatic Illustration of a Common Water Side Boiler Package

The components which always are inspected during the boiler shut down period has been identified by green circles (Steam and water drums) and green rectangular (Bank Tubes & Down Commers).

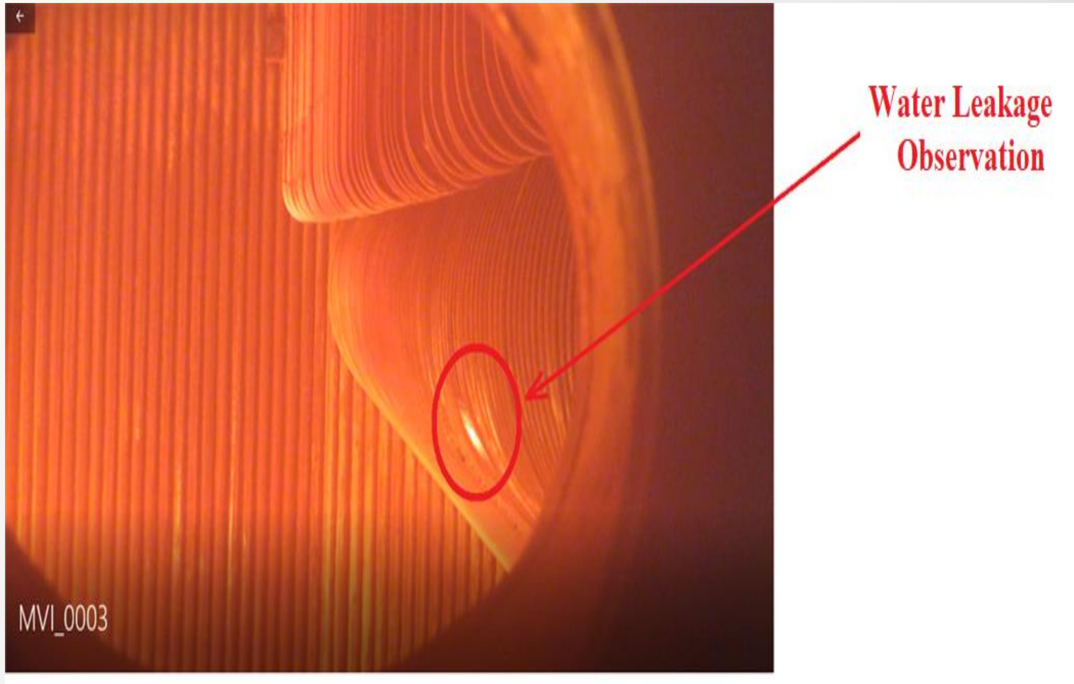
Red rectangular which indicates "superheater tubes" is not normally in the inspection plans because every body thinks that there is no probability of corrosion due to having superheated steam and not having water in liquid phase. This is a misleading thought because severe corrosion loss can be experienced in U-bends of these superheater tubes. A 'Silent Corrosion" without any alarm which is able to end in premature failure and unwanted shutdown. And this the significance of field experience in the assignment of damage mechanisms for the components susceptible to corrosion. RBI implementation without this knowledge could be useless.



Failure Observation

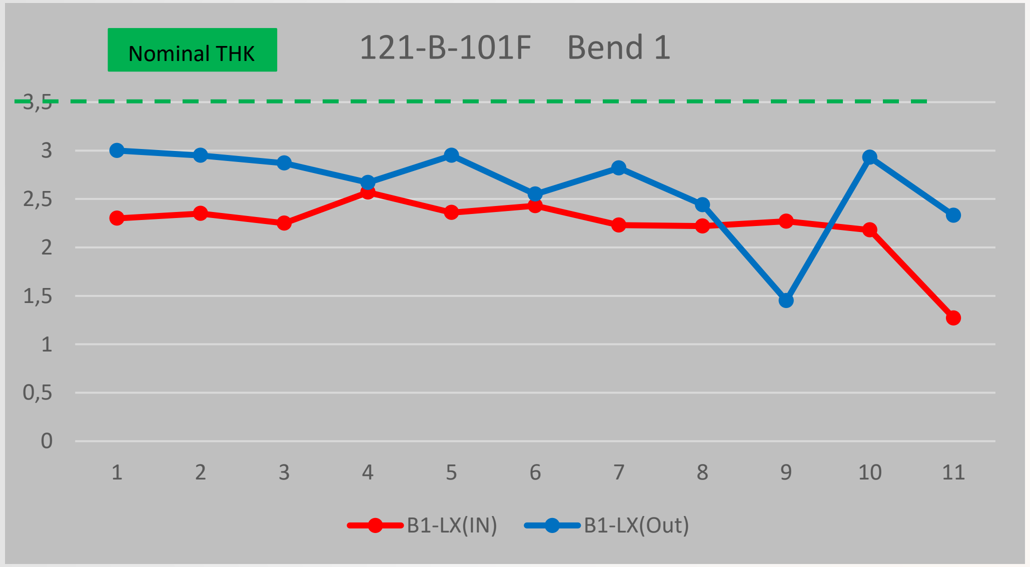
In the right photo you can see the leakage that we observed from sight glass of one of the boilers when it was at service.

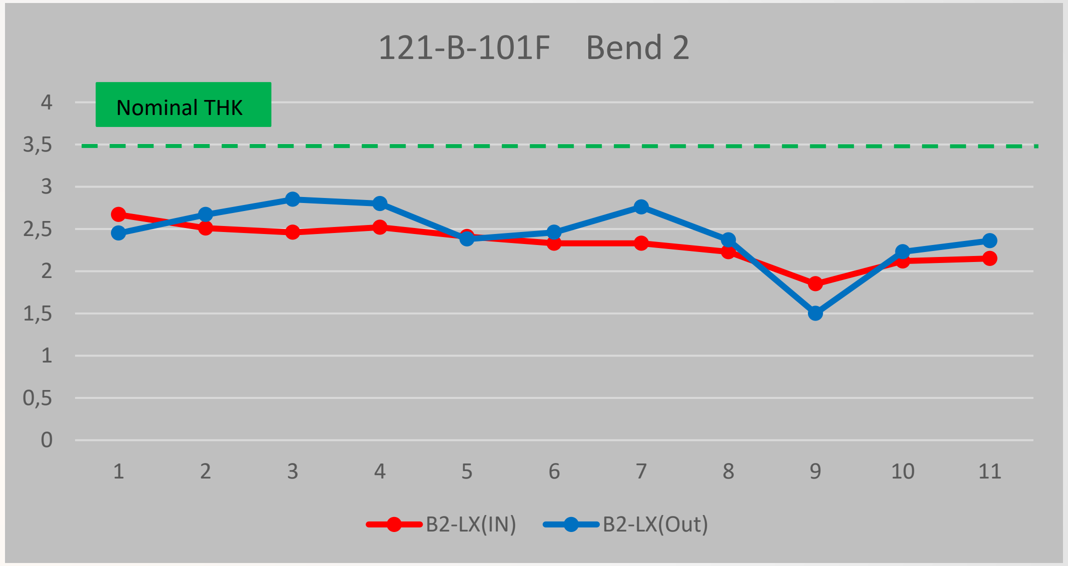
After leakage observation, the boiler was stopped and hydrotest was performed in order to find out the leakage source. As you can see in the left photo, a leakage was detected in one of the U-bends of the super heater tubes. So, it was decided to conduct UT-Scan in all the U-bends of the superheater tubes to evaluate the probability of thickness loss and corrosion pattern in this components.

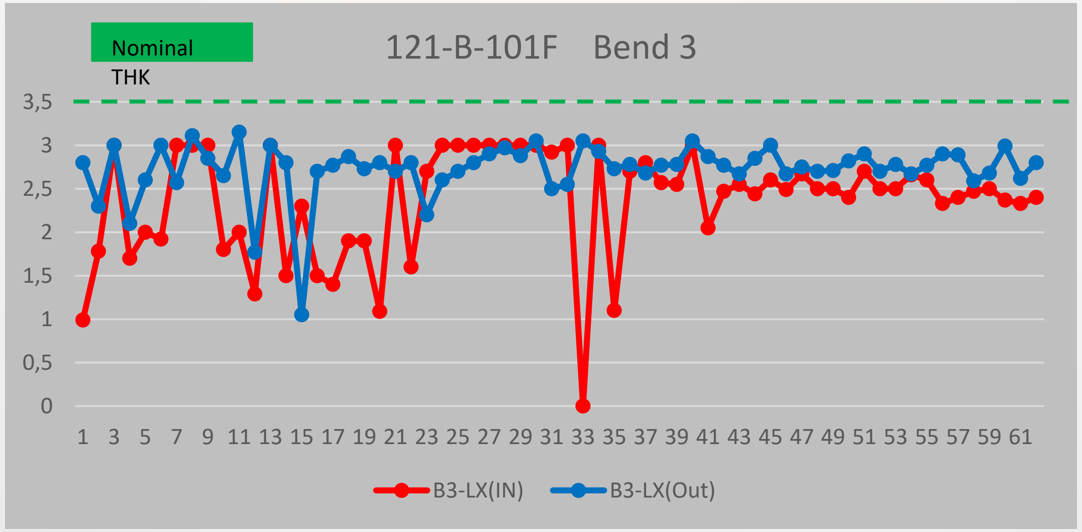


• Results of UT-Scan on U-bends of Superheater Tubes

The nominal thickness of the tubes is 3.5 mm with 1.5 mm of corrosion allowance. As it is obvious, thickness loss was happen in all U-bens and only one of the tubes experienced leakage.

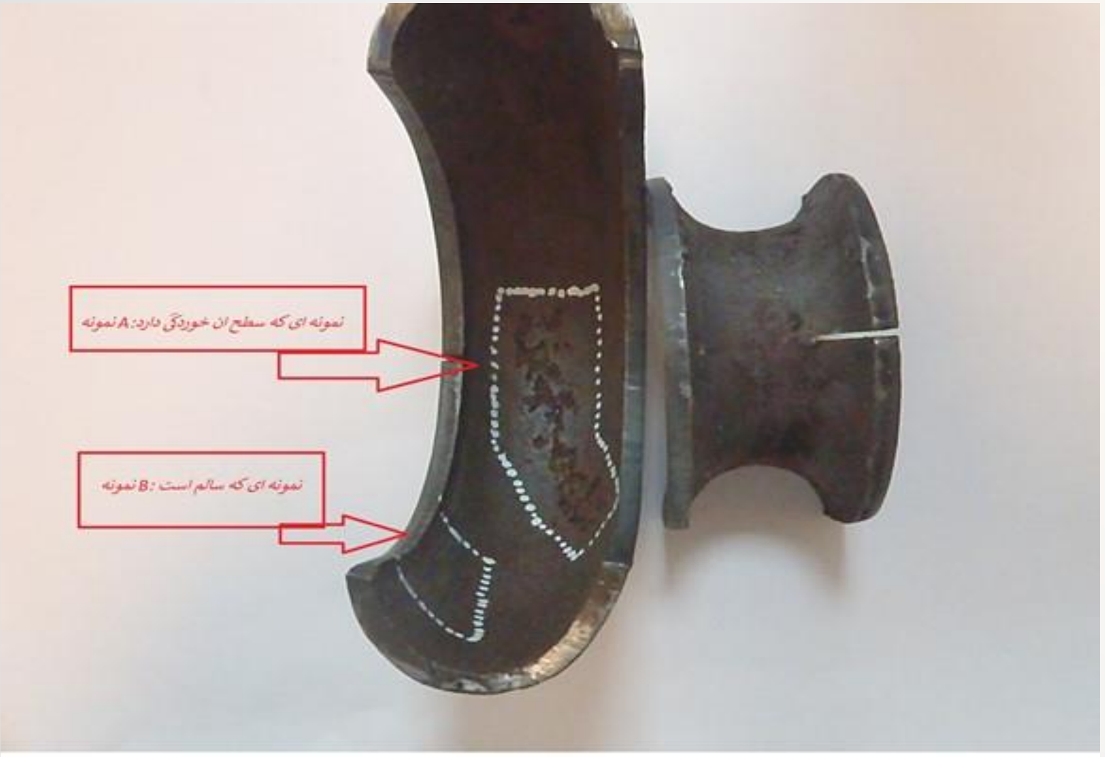






• Taking Sample & Cutting to observe inside status

One of the tubes at the U-bend section was cut and sectioned in order to investigate the corrosion pattern inside the tube. Tube material is according to standard ASTM A213 –T11 and the material was confirmed by PMI.



• Probable Scenarios for Root Cause Analaysis:

Probable corrosion mechanisms based on the morphology of this corrosion can be ascribed to under deposit corrosion as:

- Caustic attack (caustic gouging) (if Na/phosphate ratio exceed 3)
- Acid phosphate corrosion (if Na/phosphate ratio goes under 2.2)

All of these mechanisms need deposits and a concentration mechanism within those deposits.

Load changes can result in “phosphate hideout” and consequent free caustic formation and phosphate precipitation.

Boiler water cary-over from steam drum into the superheated tubes and accumulation of this carry-overed waters in U-bends and steam blanketing process and also evaporation of this water and salt concentration could be results in the Caustic Gouging or Acid Phosphate Attack in U-bends.

- **Mechanisms of Corrosion by Caustic or Acid Phosphate Attack:**

Caustic Gouging

At temperatures above 90 C, the concentrated NaOH attacks into the protective magnetite film by the following reactions:

$$\boxed{Fe_3O_4 + 4NaOH \rightarrow 2NaFeO_2 + Na_2FeO_2 + 2H_2O}$$

$$\boxed{3NaOH + Fe_3O_4 \rightarrow 3NaFeO_2 + H^+ + H_2O}$$

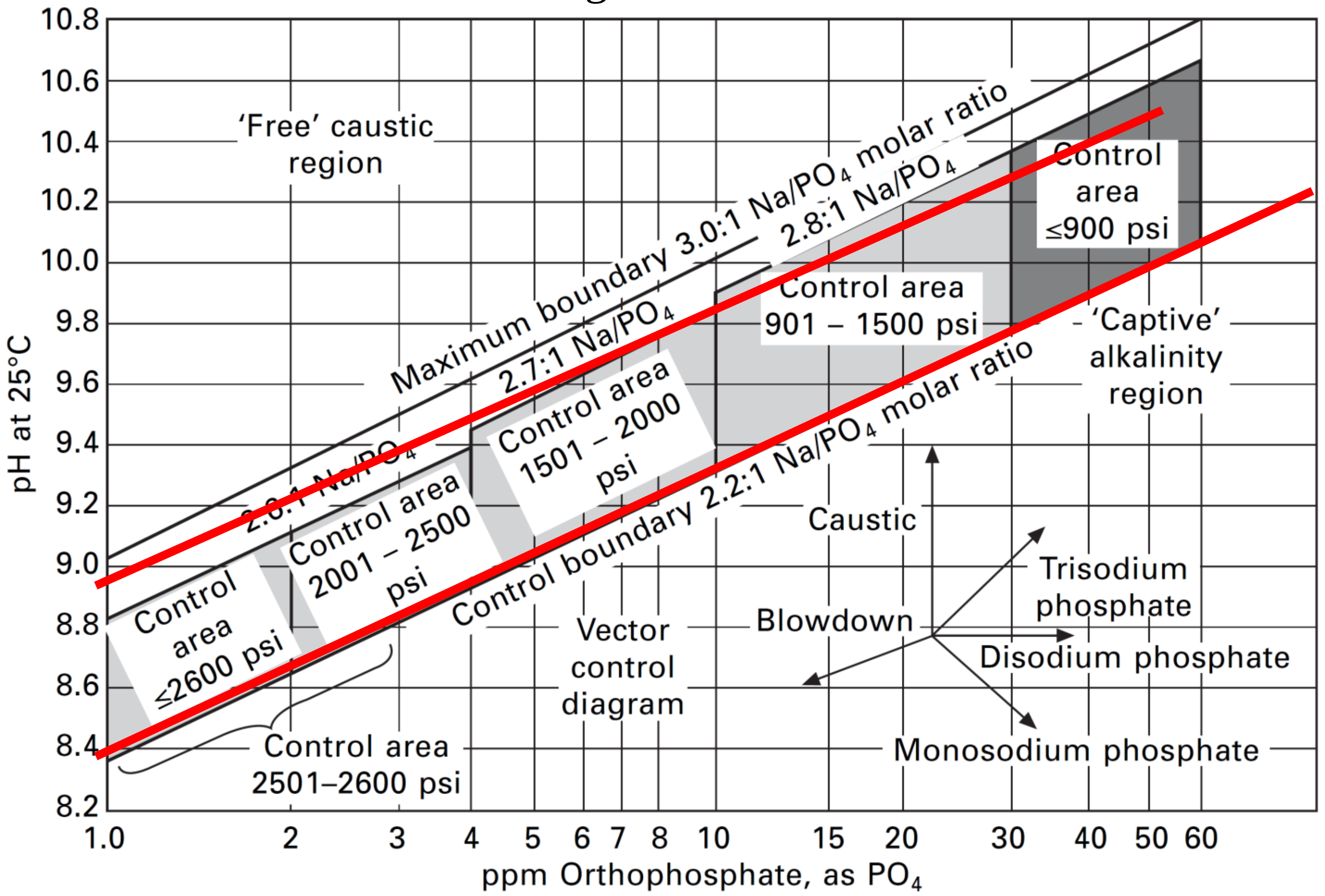
Gradually, the highly concentrated NaOH dissolves the protective magnetite layer based on above reactions, and the bare iron reacts with NaOH according to the following reactions and corrosion of base metal is taken place by gouging.

$$\boxed{NaOH + H_2O + Fe \rightarrow NaFeO_2 + 3H^+}$$

$$\boxed{2NaOH + Fe \rightarrow Na_2FeO_2 + H_2}$$

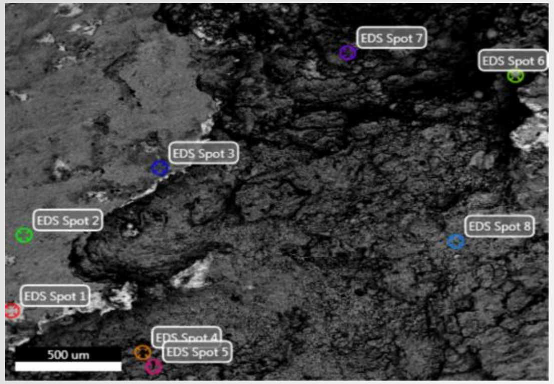
• IOW (Integrity Operating Window) for boilers with Phosphate treatment

In below diagram, IOW with upper and lower thresholds to prevent “Caustic Gouging” and “Acid Phosphate Attack” has been illustrated. Upper and lower thresholds in this safe window are 3 and 2.2 respectively. if Na/phosphate molar ratio exceed 3, “Caustic Gouging” damage machanism will be active and in case that Na/phosphate molar ratio is less than 2.2, “Acid Phosphate Attack” can be active. Both of these damage mechanisms need concentration whithin deposits.



14.6 Coordinated phosphate/pH control graph. Source: Betz Laboratories (1991).

• EDX Results on Corroded Area



SEM image from one part of the corroded area has been shown in above photo.

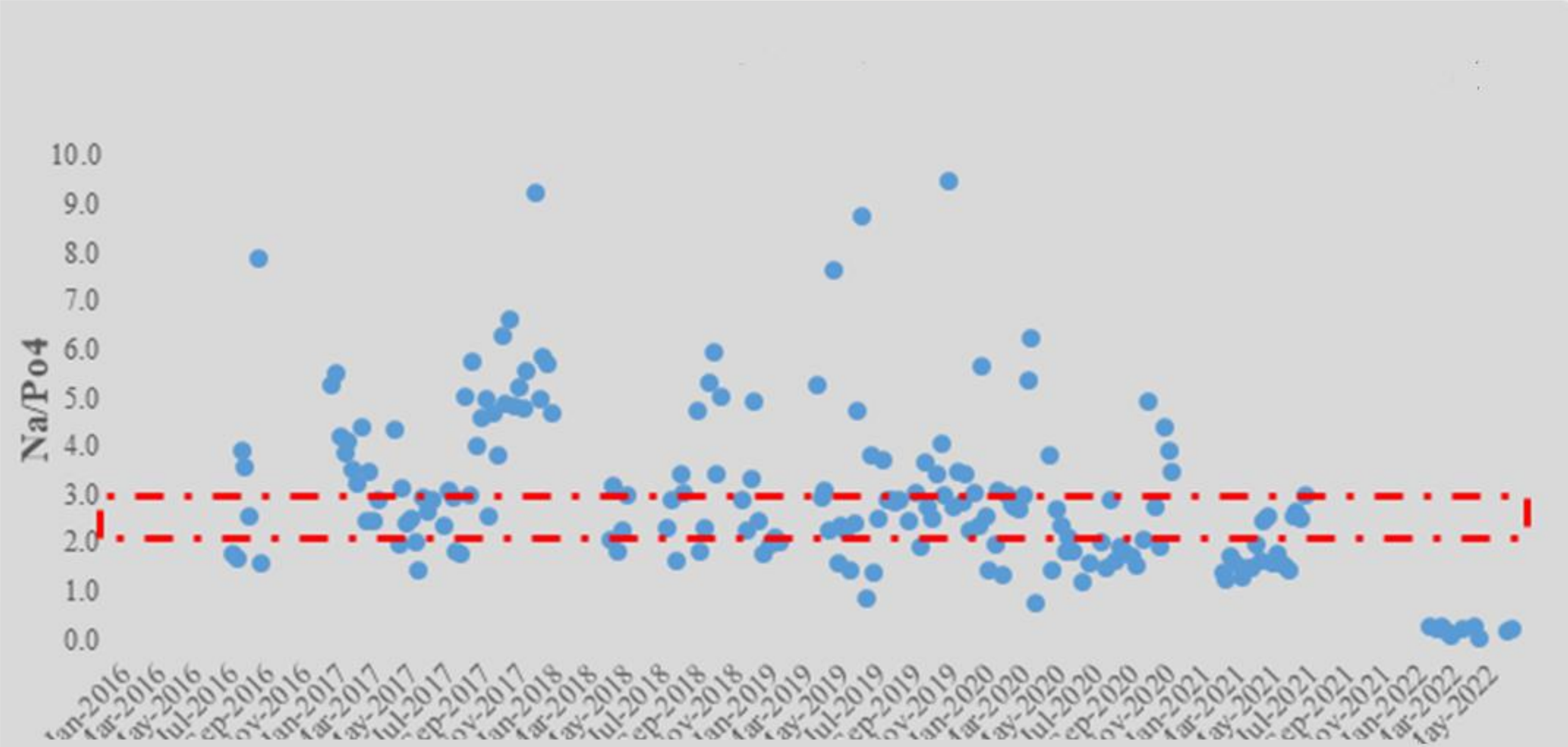
EDX results from inside the corroded area has been illustrated in the right table. Comparing the elements of this tables with the elements of parrent metal (blue table) indicates some elements like Oxygen and Na which are not as the elements of parrent metal and have external sources.

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
O K	4.17	12.82	81.17	9.73	0.0206	1.2311	0.8669	0.4018	1.0000
NaK	1.50	3.20	8.49	28.75	0.0018	1.1299	0.8977	0.1045	1.0017
AlK	0.02	0.05	0.43	99.99	0.0001	1.1129	0.9162	0.2503	1.0056
SiK	0.50	0.88	12.65	29.58	0.0021	1.1402	0.9248	0.3598	1.0092
P K	0.01	0.01	0.14	99.99	0.0000	1.0977	0.9331	0.4774	1.0153
MoL	0.03	0.02	0.62	75.82	0.0002	0.8907	1.1193	0.7904	1.0345
S K	0.12	0.19	4.40	65.28	0.0008	1.1217	0.9411	0.5955	1.0242
ClK	0.08	0.12	3.18	64.05	0.0006	1.0693	0.9488	0.6953	1.0382
CaK	0.36	0.44	13.78	26.91	0.0039	1.0900	0.9706	0.8925	1.1275
CrK	1.58	1.49	59.37	12.39	0.0233	0.9858	0.9962	0.9846	1.5226
MnK	0.83	0.75	20.78	24.58	0.0092	0.9670	1.0021	0.9936	1.1448
FeK	90.80	80.05	1840.20	1.64	0.9123	0.9845	1.0076	0.9958	1.0248

Tube Material's Grade	C	Mn	P	S	Si	Cr	Mo
ASTM A213 T11	0.05-0.15	0.3-0.6	0.025	0.025	0.5-1	1-1.5	0.44-0.65

• Lab results of Na/PO4 molar ratio

Laboratory results (below graph) indicated that Na/PO4 molar ratio in 50% of cases from the start-up of this boiler was out of the safe IOW. Exceeding this ratio from 3, activates “Caustic Gouging” damage mechanism which can cause corrosion in the case of concentration (Such as under deposits after evaporation of water and salt concentration or at the “water line” in horizontal or slanted tubes which are not full of water).



Conclusions:

- RBI implementation without the field knowledge of the probable damage mechanisms in the steam generation boilers is a useless effort and POF calculation as the base step in risk analysis is very important.

- EDX results & history of laboratory results of Na/PO4 molar ratio confirmed the "Caustic Gouging" as the root cause of the corrosion.

- As you see, the leakage and failure was occurred in a component that never been in the inspection plan (Superheater Section), and this reveals that without having field experience and without defining the probable potential damage mechanisms the RBI calculations for steam generation boilers would be useless.

- This Localized thinning shall be considered in superheater tubes as a potential damage mechanism in calculation of damage factor & POF in RBI Methodology.

- An IOW shall be defined and monitored for Na/PO4 molar ratio in blow-down water samples from steam drum in order to prevent "Caustic Gouging" and "Acid Phosphate Attack" in boiler systems.

- Effective inspection method is to conduct Scan-UT on U-bends of superheatrr tubes and inspection interval is related to the last results of thickness measurement.

Appendix 11

Wet H2S Cracking Update

(Gerrit Buchheim)

EUROCORR AUGUST 27 - 31, 2023 BELGIUM BRUSSELS
THE ANNUAL CONGRESS OF THE EUROPEAN FEDERATION OF CORROSION

BECHT
Good. Better. Becht.™

Wet H2S Cracking Update

Gerrit Buchheim

ENGINEERING SOLUTIONS | PLANT SERVICES | SOFTWARE TOOLS | LEARNING & DEVELOPMENT

Topics

SOHIC in Seamless Piping

History for wet H2S cracking

What to Inspect and How

API 579 Efforts

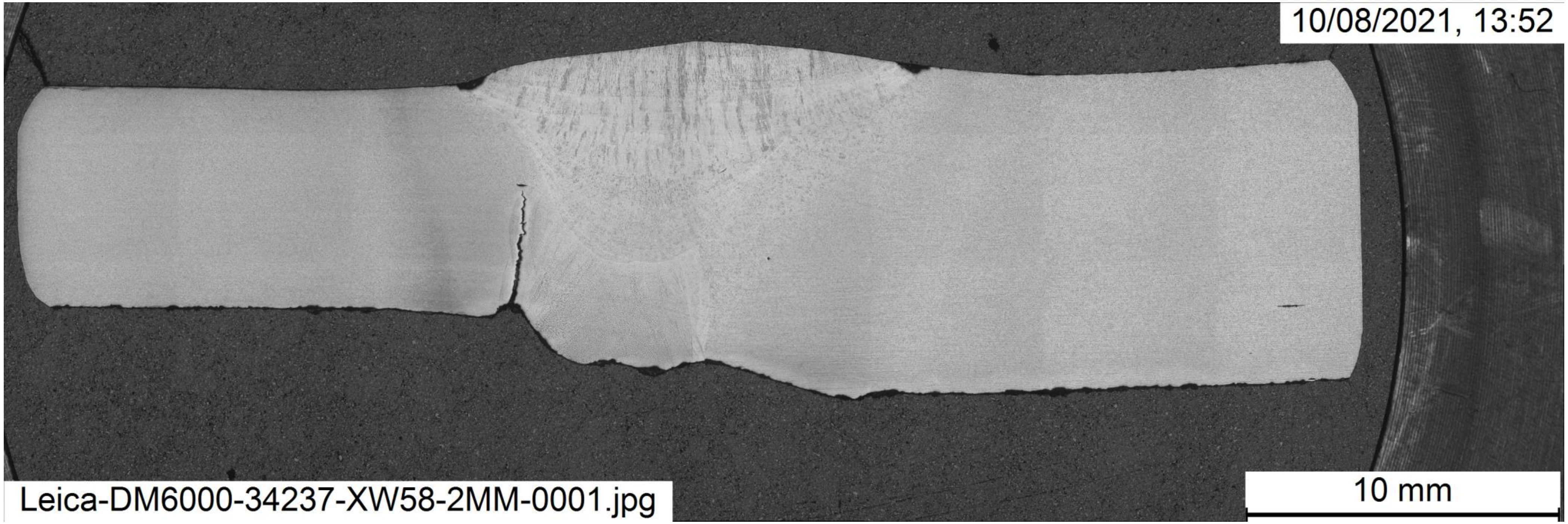
Presenter Biography

- Gerrit Buchheim, P.E.
- Becht - Materials and Corrosion and Integrity Management Division Manager and Refining Expert
- 44 Years Refining Experience (20 yrs for oil companies, rest consultant)
- Expert in Wet H2S Damage. Examined Union Oil samples and have guided numerous Inspection, FFS, and repair work
- API 579-1/ASME FFS-1 Part 7 (Blistering/HIC) chair since inception, numerous publications, NACE (AMPP) vice chair of SP-02-96
- Involved in API RBI (before API 581)Tech Modules, inc. Wet H2S
- Created numerous inspection/assessment/repair guides for refineries for wet H2S Cracking

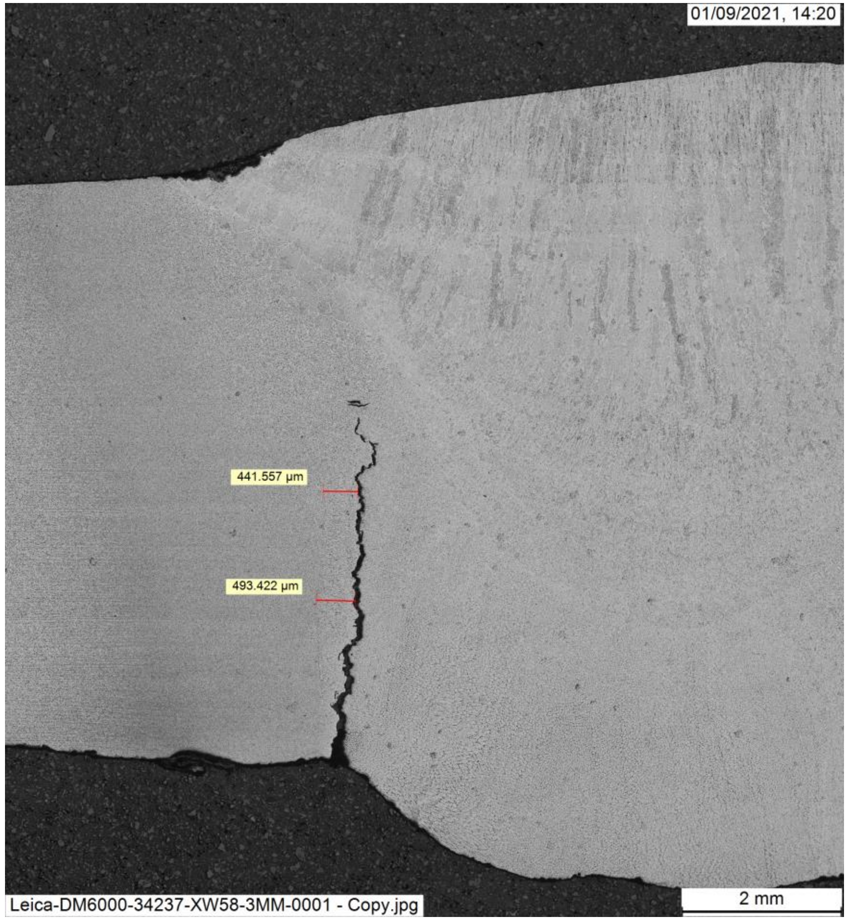
SOHIC of Seamless Piping

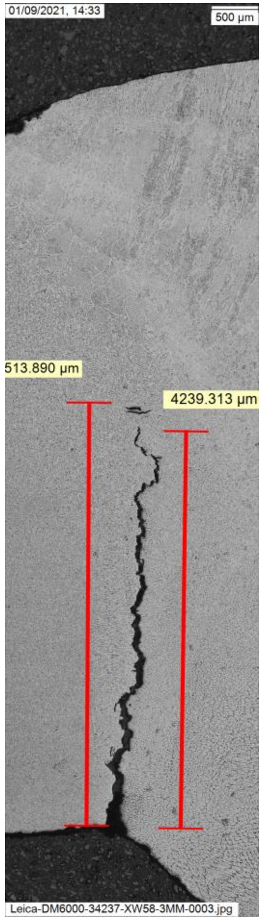
- FCC Light Ends after Wet Gas Compressor
- A106 Grade B piping 10-14 cm diameter
- No obvious issues with inclusions, looks clean
- Incredibly high amounts of CN. Normally consider CN there (like 20 ppm) or not (0 to 5 ppm). CN measurements are very difficult, but in this unit ranged between 100-500 ppm routinely
- Had a leak and inspected and found damage adjacent to majority of the circumferential welds
- In most risk assessments seamless piping that is single sided welded is considered immune from HIC/SOHIC cracking. There have been some failures in seamless piping in upstream, but not aware in refineries

Seamless Pipe



Seamless Pipe





Bit of History

- Romeoville Union Oil Absorber SOHIC failure in 1984 changed the industry
- NACE SP02-96 has original data from mid to end of 1980's survey data. Vessels wre first time inspected with very sensitive surface inspection technique WFMT (came form deaerator failures) and were finding cracks in majority of equipment.
- Once people knew they would be using such sensitive techniques after service companies started to inspect as built vessels and found many to be cracked
- Quality improved, although weld defects associated with nozzles is still common.
- Three major forms of wet H2S cracking(hard weld and hydrogen charging related).
- Newer vessels constructed with PWHT

What Has Been Industry Experience?

- Challenging to collect true failure rates/data
- There have been other through wall failures, but given the population of "wet H_2S service" vessels the number is miniscule.
- NACE Refincor and API/AFPM records show a few failures, but not many. Often damage is found, but even damaged equipment has an incredible ability to withstand damage
- When formulated API 581 we did differentiate between susceptibility and severity and damage factors are lower for wet H_2S damage than other SCC mechanisms.
- Given that most people define wet H_2S service as 50 ppm H2S in water phase, an incredible number of equipment items are potentially subjected to wet H_2S damage. I believe this is too conservative.
- Inspection targets the appropriate damage mechanism so if "wet H_2S damage is identified as a DM they will inspect for that. Lots of minor cracking will be found and repaired, but does not have any appreciable affect on risk

What to Inspect and How?

- We know from experience that things like CN, high velocities, and cleaning surfaces for WFMT inspection help remove any protective FeS layer that forms in such services.
- Canary in coal mine is the philosophy I espouse when it comes to wet H2S inspection
- Focus on high risk, high likelihood vessels or large diameter welded piping:
  - FCC Light ends after wet gas compressor (sponge absorber, deethanizer)
  - Coker Light ends
  - Hydrotreater/cracker high pressure cold separator and stabilizer overhead drum
  - Amine absorbers (high pressure)
- Hydrogen charging and damage is more event based than time based.
- PAUT TFM is finding more damage than UT shearwave, but some inspections are actually too high a gain and sensitive resulting in overcalls
- Lots of FFS

API 579-1/ASME FFS-1 Part 7

- HIC Rules are deemed conservative
  - Both crack-like flaws
  - Loss of Strength
- The testing we did for API 579 Part 7 showed that remaining strength of badly damaged steel exceeds about 50% of its true value
- Been working at ways to reduce conservatism
  - 0.2 RSF or DF (0.8)
  - Based on WRC 531 testing
  - Found that most data was worst case 50% loss
  - Recent work by ExxonMobil and Shell show
    - Severe charging about 80% loss (both new and old)
    - Moderate charging about 50% loss
    - Mild charging more like 30% loss

Appendix 12

Case study: a persistent corrosion problem located near a complex arrangement of pressure relief valves

(Säle Eide)

Case study: a persistent corrosion problem located near a complex arrangement of pressure relief valves

EuroCorr, August 2023

EMERSON

From Corrosion Risk to Integrity Managed

1 Corrosion Risk Identified, but Root Cause Not Understood

2 Corrosion Monitoring Implemented

3 Likely Root Cause(s) Identified and Corrosion Managed

Application – Refinery Crude Distillation Tower Overhead System

- After severe thinning in the area after an injection quill, the overhead system was redesigned and a number of Permasense UT sensors was installed in typical material loss positions and specially after one of the chemical injection quills in the new overhead system.

- Permasense UT sensors was installed near to the Injection Quill to assess if different crudes, inhibition rates and operating conditions could affect internal corrosion with corresponding material loss.

Emerson Corrosion System – Sensors After Injection Quill Showed Elevated Thickness Loss Rates

Addresses | Measurement Points | Users | Diagnostics | Site Settings | Help

Area 3 Measurement Points

permasense® powered by AXC

Table | Multiple Graphs | Metal Loss Heatmap | Logged in as: joni | Log-out

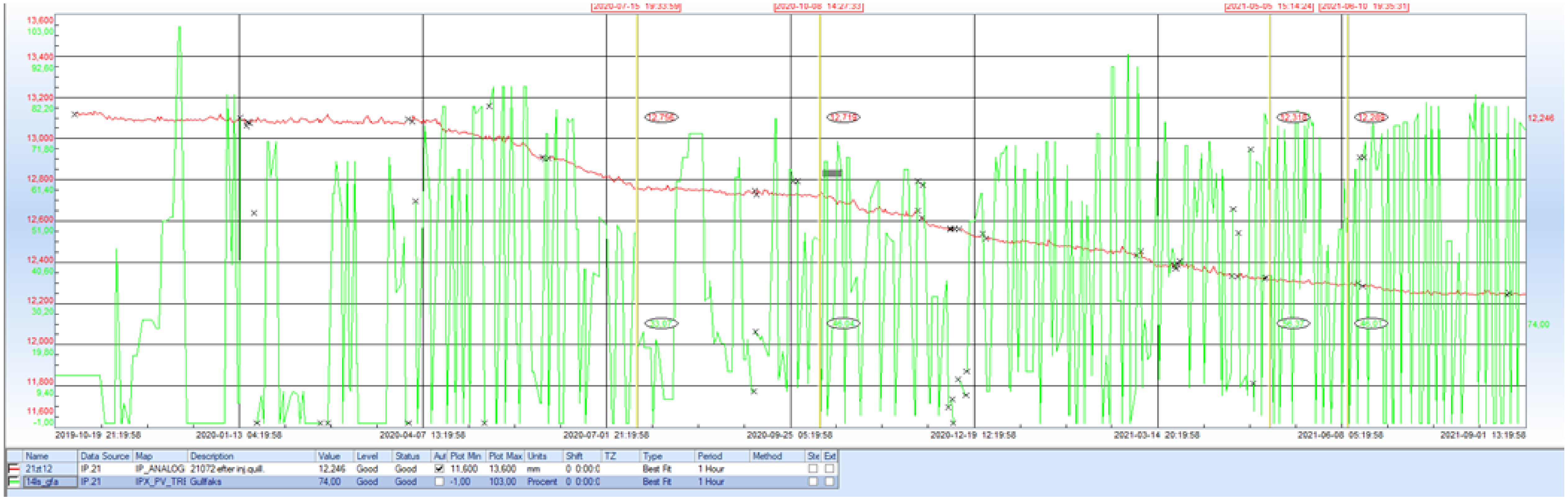
ADDRESS: PREEMRAFF LYR / AREA 3

FILTER: AMBER DATA RECEIVED ONLY ×

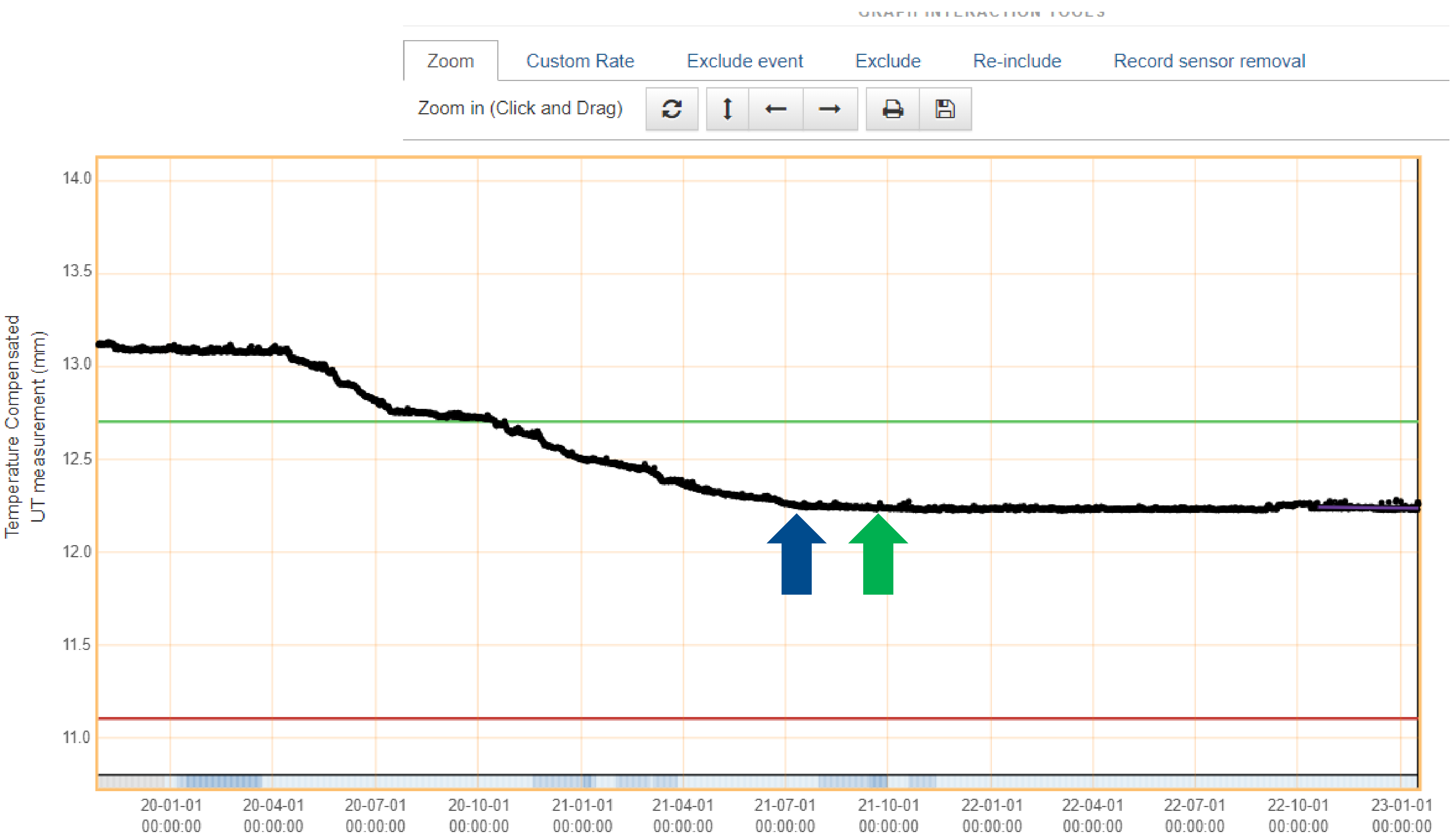
Select columns ▾ | Showing 1 to 19 of 19 entries | Filter: | Show 20 entries

Rec.	Address	Identifier	Name	MAC Address	Flag	7 day average (mm)	Remaining thickness (mm)	Last thickness (mm)	PSI	12 Months Rate (mm/yr)	12 Months Classification	3 Months Rate (mm/yr)	Actions
	T2101	21ZT17	21072 36" 05:30...	GFNF		10.22	-0.88	10.22		0 ± 0		0.01	
	T2101	21ZT15	21072 36" 06:00...	GFH2		12.97	1.87	12.97		0.01 ± 0		0	
	T2101	21ZT13	21072 36" 06:00...	GFND		13.11	2.01	13.1		0 ± 0		0	
	T2101	21ZT10	21072 36" 06:00...	GFMT		NO DATA	NO DATA	12.93		NEED DATA		NO DATA	
	T2101	21ZT8	21072 36" 06:00...	GFMB		12.96	1.86	12.96		0.05 ± 0.01		0	
	T2101	21ZT6	21072 36" 06:00...	GFM9		13.03	1.93	13.04		0.02 ± 0		0.01	
	T2101	21ZT4	21072 36" 06:00...	GFK3		12.99	1.89	13		0.01 ± 0		0	
	T2101	21ZT16	21072 36" 06:30...	GFME		10.61	-0.49	10.62		0.01 ± 0		0.04	
	T2101	21ZT3	21072 36" Upper...	GFN4		NO DATA	NO DATA	12.12		NEED DATA		NEED DATA	
	T2101	21ZT2	21072 36" Verti...	GFMH		10.36	2.43	10.36		0 ± 0		0.01	
	T2101	21ZT1	21072 36" Verti...	GFN0		10.28	2.35	10.28		0 ± 0		0	
	T2101	21ZT11	21072 efter inj...	GFN3		13.63	2.53	13.63		LOOK AT DATA		0.03	
	T2101	21ZT12	21072 efter inj...	GFN7		12.24	1.14	12.23		0.35 ± 0.01		0.04	
	T2101	21ZT14	21218 10" (21SV...	GFKH		9.13	1.71	9.12		0 ± 0		0	
	T2101	21ZT9	21222 12" (21SV...	GFKB		9.55	1.62	9.54		0.01 ± 0		0.01	
	T2101	21ZT7	21224 12" (21SV...	GFMY		9.81	1.88	9.81		0 ± 0		0	
	T2101	21ZT5	21522 12" (21SV...	GFMA		9.41	1.49	9.41		0 ± 0		0	
	Unit 220	22ZT1	22064 TVGO retu...	GFMN		8.5	4.08	8.5		0.03 ± 0		0.02	
	Unit 833	83ZT1	83306 efter vor...	GFH9		7.05	3.14	7.06		0.02 ± 0		0.02	

Trending Using AspenTech IP.21 – Metal Loss Is Correlated With More Agressive Blending, but Did Not Stop!



Trending of WT210 Thickness Sensor Closest To Injection Quill



Stopped amine neutralizer injection

Replaced broken injection quill

Operations Results Obtained

- Avoided unexpected shutdowns as a result of the increased corrosion rate
- Allowed an effective preventative maintenance strategy, saving time and money
- Ensure the longevity and integrity of fixed equipment using quantitative corrosion calculation

"Using Permasense and AspenTech IP.21, we quickly detected and diagnosed the root cause of corrosion, and took effective measures to prevent it from happening again. This avoided further unplanned outages, saving time and money"

References and Thanks

- Joakim Nilsson, Corrosion Engineer – Preem
- Will Fazackerley , Global Product Manager - Emerson

Appendix 13

How to treat a CWS with very low mineralized water

(Valerie Bour-Beucler)

How to treat a CWS with very low mineralized water

Valerie Bour Beucler

August 29, 2023

World new challenges

- Climat influence
- Water discharge
- Water availability and water restriction in some area and countries
- Regulation
- Treatment selection (corrosion inhibitors)

Water will become different from just a commodity in industrial water

No P, M

No P, No M
Low P, no M

Low P, M

Actual versus Tomorrow

CWS treatments

Actual situation

- ✓ Water losses (leaks, process)
- ✓ Cycle control / investment
- ✓ Traditional anodic corrosion inhibitors (P) associated to cathodic inhibitors (zinc or others)
- ✓ Treatment adapted to make up water quality and working windows, pH control or not

Tomorrow

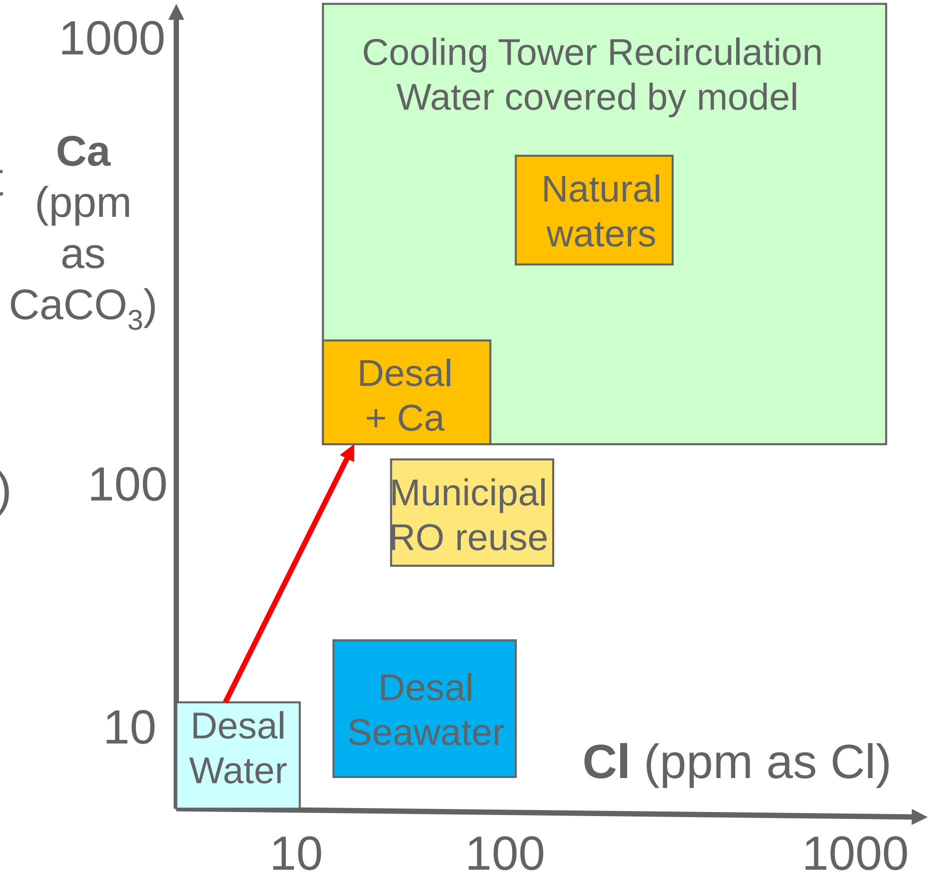
- ❑ Water savings (reuse, water consumption reduction), pretreatments with RO….
- ❑ New treatments without P and M
  - ❑ Carboxylates, dispersant family
  - ❑ Water will be adapted to new chemistry (efficiency)

Desalinated Water: new cooling make-up

Unnatural water sources not covered by conventional models & historic experience

Increasingly considered as cooling tower make-up

- Different from traditionally used surface water, outside of treatment model area for corrosion
- Corrosive to mild steel
- No buffering capacity/alkalinity (pH swings)
- Hardness remineralization typically required (compromising cycles)
- Corrosive to copper alloys if recycled municipal wastewater
- **Innovation** applied to arrive at robust treatment strategies, adapt remineralization to treat with a good control on corrosion.
- Very soft water cannot be used without remineralization.
- Calculated scenarios are required.



Increasing use of Desalinated Water

Water scarcity is driving production sites to review cooling tower make-up sources

- Raw water sources
  - **Treated Sewage Effluent**
  - Industrial Wastewater
  - Seawater
  - Brackish/tidal/harbor water
- Water production process
  - **Reverse Osmosis**
  - Ion exchange
  - Lime softening

Improving the Water Quality

- Buffer capacity increase by adding
  - Sodium bicarbonate, Sodium carbonate….
- Calcium hardness may be added by:
  - Calcium nitrate (discharge limit may apply)
  - Calcite/Dolomite filters
- **Blending in river water alternative to the above**

Remineralized water is very important and the key of the success to have corrosion under control

Desalinated Water: Risk of Corrosion

Unnatural water sources not covered by conventional models & historic experience

- Lack of buffering capacity and calcium carbonate accelerates the corrosion reactions exponentially
  - Corrosion produces acid, localised pH dip, more corrosion
  - Ca is needed in the inhibitor mechanism
  - Calcium carbonate balance
- Soft iron oxides allows continued metal dissolution
- Chlorides in unbuffered waters accelerates corrosion

Remineralized water is very important and the key of the success to have corrosion under control

Conclusions

Climat., water restrictions and regulation will change CWS strategy, treatments and make up water.

New treatments will required a soft water with remineralization, make up water quality will be adapted and not the opposite as today.

New treatments will be no P and No M.

Water losses and cycle control will be a real target for CWS management

Pretreatment will be part of the CWS strategy.