



ICorr Birmingham 2023.

Thurs 9th February 2023

Birmingham Council Chambers – ‘Free to Attend FTF Event’



Programme - A Special Awards-Driven Event covering 4 Main Themes – Electrochemistry, Cathodic Protection, Production Chemistry and Protective Coatings.

Thurs 9th February 2023

Birmingham Council Chambers

11.00 - 11.30	Arrive: Registration and Networking, Tea and Coffee served in the Chamberlain Room.
11.30 - 11.40	Welcome from Bill Whittaker, Event Co-ordinator
11.40 - 11.50	Welcome from the ICorr President, Stephen Tate
11.50 - 12.40	<p>Session 1 - ICorr Award Winners Talks in the Chamber:</p> <ul style="list-style-type: none"> • Alison Davenport – Pitting: the delicate balance between dissolution and passivation. • Chris Lynch – Cathodic Protective Standards Making.
12.40 - 13.30	Lunch in the Chamberlain Room.

<p>13.30 – 14.20</p>	<p>Session 2 - Symposium Speakers in the Chamber:</p> <ul style="list-style-type: none"> • Ken Lax – BS EN ISO 21857:2021 Prevention of corrosion on pipeline systems influenced by stray currents. • George Winning – Latest Innovations in Production Chemistry.
<p>14.20 - 14.40</p>	<p>Tea and Coffee Break - Networking in the Chamberlain Room.</p>
<p>14.40 – 16.00</p>	<p>Session 3 - Symposium Speakers in the Chamber:</p> <ul style="list-style-type: none"> • Chris Googan – Why do Protective Coatings Fail? • Simon Daly – Challenges for Selecting Coatings for the fixed and floating offshore wind industry. • Malcolm Morris – Update on International Standards Activity Within the Protective Coatings Sector.
<p>16.00 - 16.30</p>	<p>Close-out / Tea and Coffee Break / Networking in the Chamberlain Room.</p>

Paper 1 – Professor Alison Davenport





Bio – Professor Alison Davenport



Bio - Professor Alison Davenport is Professor of Corrosion Science at University of Birmingham School of Metallurgy and Materials and a UR Evans Award winner. After a PhD at Cambridge, she developed an interest in synchrotron methods at Brookhaven National Laboratory in the USA before returning to the UK to the Universities of Manchester and then Birmingham. She chaired the Aqueous Corrosion Gordon Conference in 2008, is a former Chair of STFC's Science Board, and was awarded an OBE for services to corrosion and electrochemistry in 2018.

Paper 1 – With **Video** **Presentations**



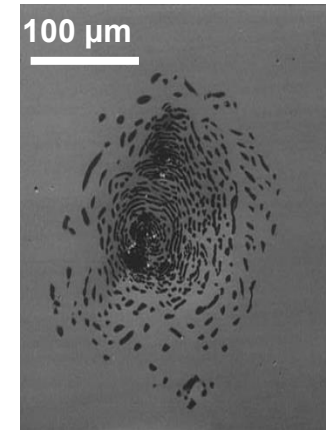
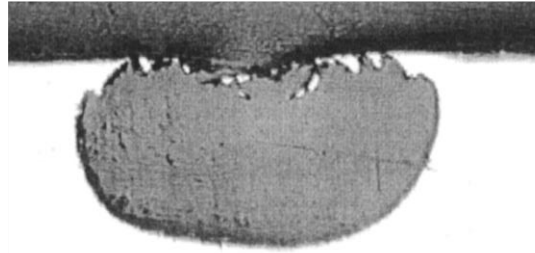
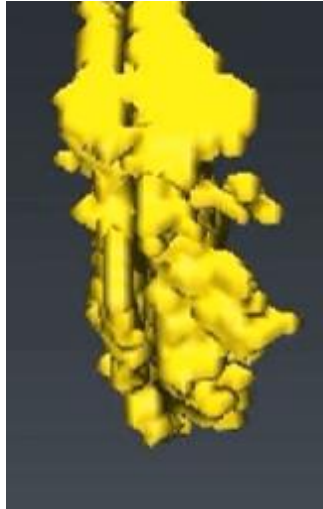
Shedding Light on Localised Corrosion

Alison J. Davenport

.... with many, many thanks to far more people than I could possibly list!



Corrosion of metals in wet environments is a non-uniform process

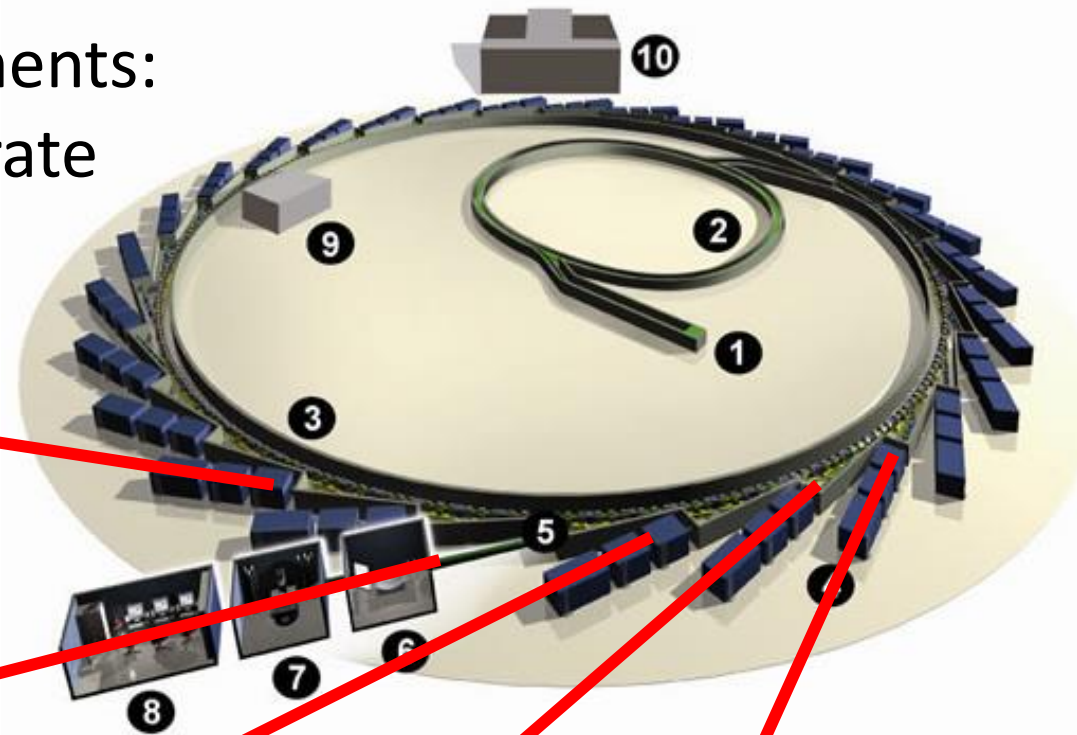


How do corrosion sites grow?

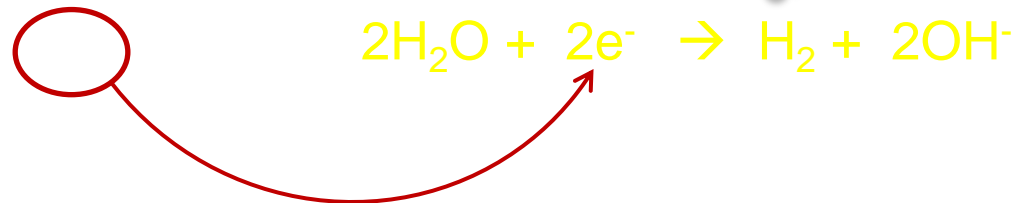
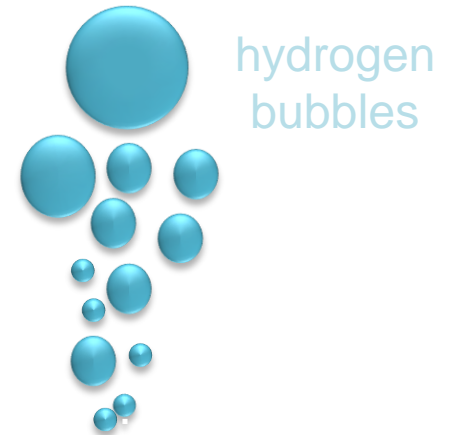
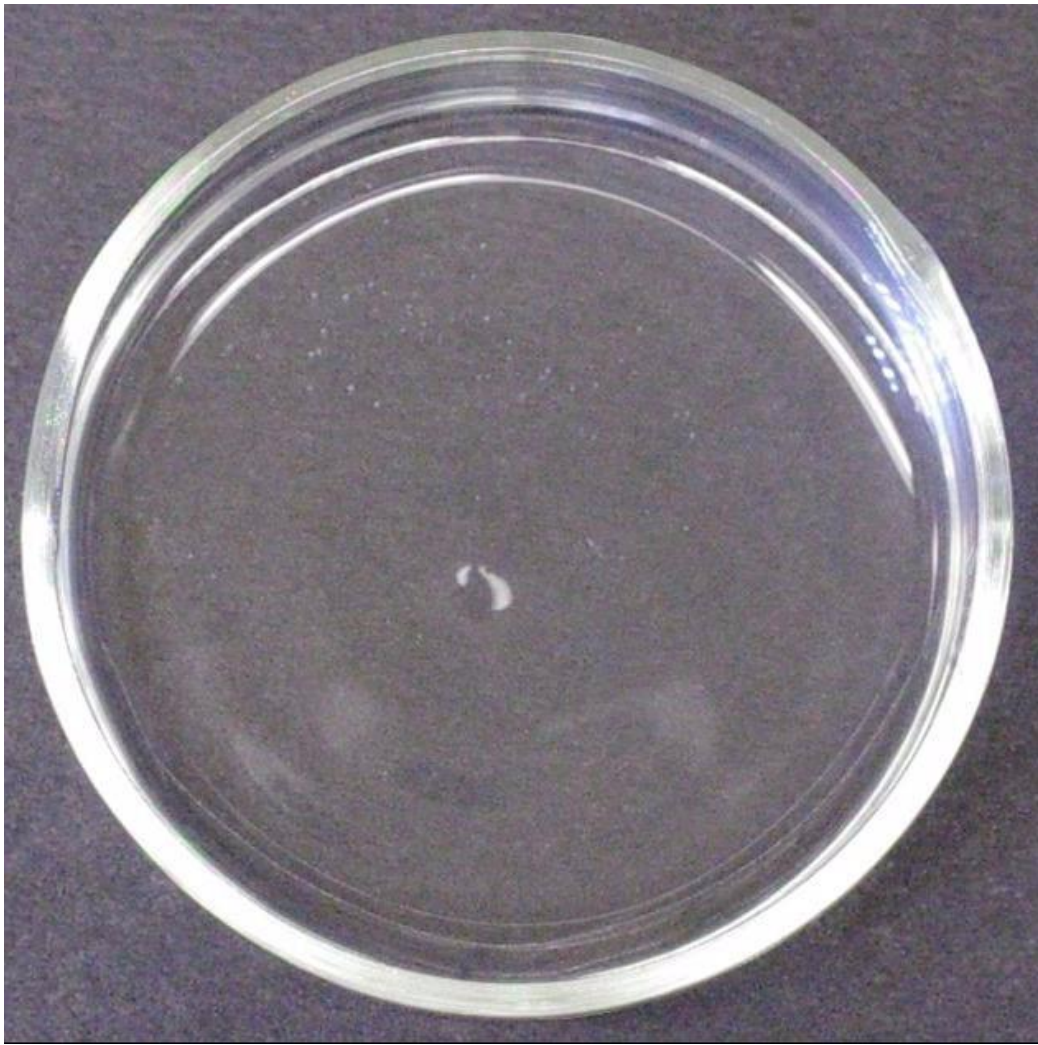
How can we follow their development in real wet environments at a microscopic level?

Corrosion in wet environments: **synchrotron X-rays** penetrate water and metal

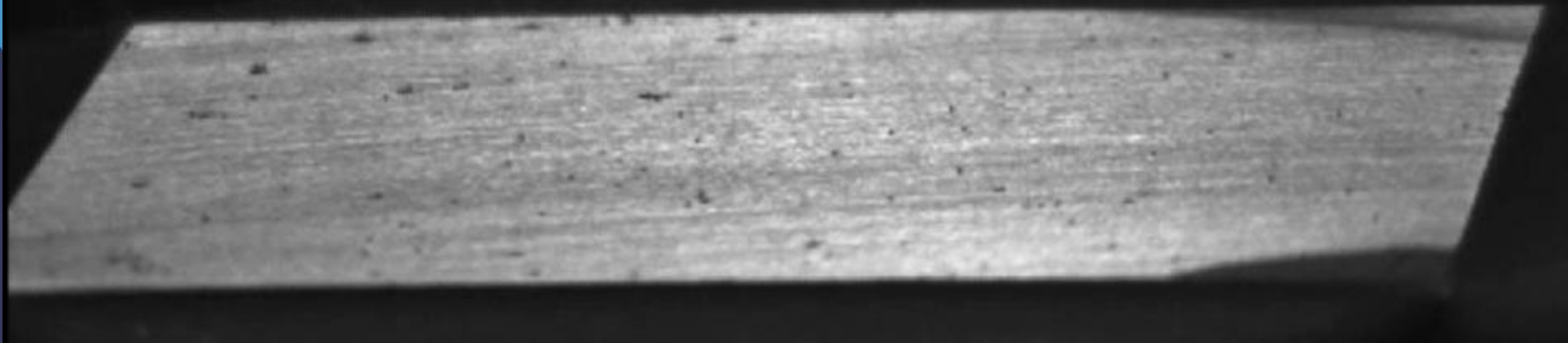
- radiography
 - 2D imaging
- X-ray microtomography
 - 3D imaging
- X-ray diffraction
 - phase identification
- X-ray absorption spectroscopy
 - oxidation state and co-ordination environment



- X-ray fluorescence
 - mapping elemental concentrations



Mg magnesium in salt water



Mg and Fe
Mg corrodes more

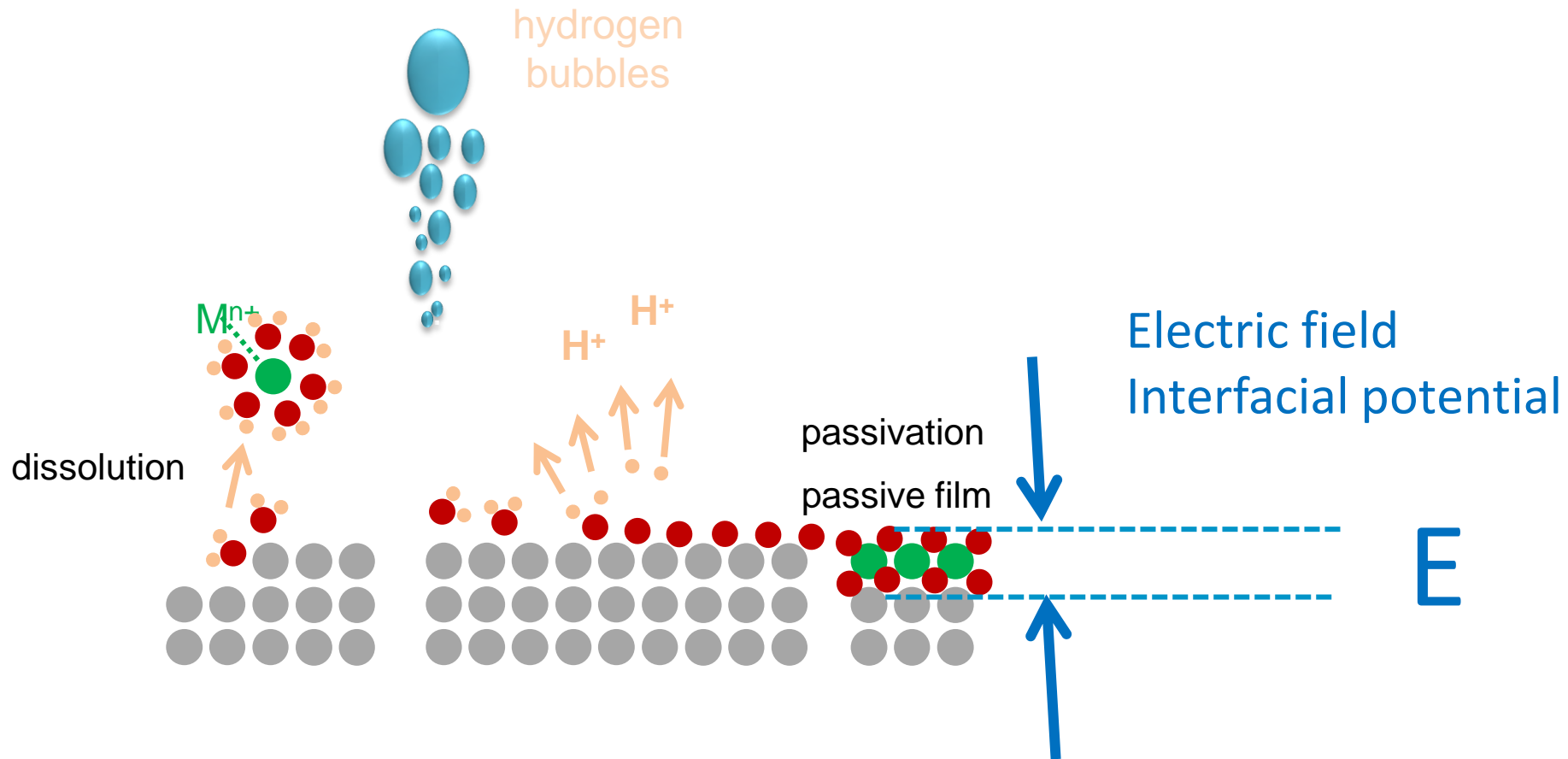
Mg (magnesium) in salt water

Mg and Na are both highly reactive
but Mg corrodes more slowly...

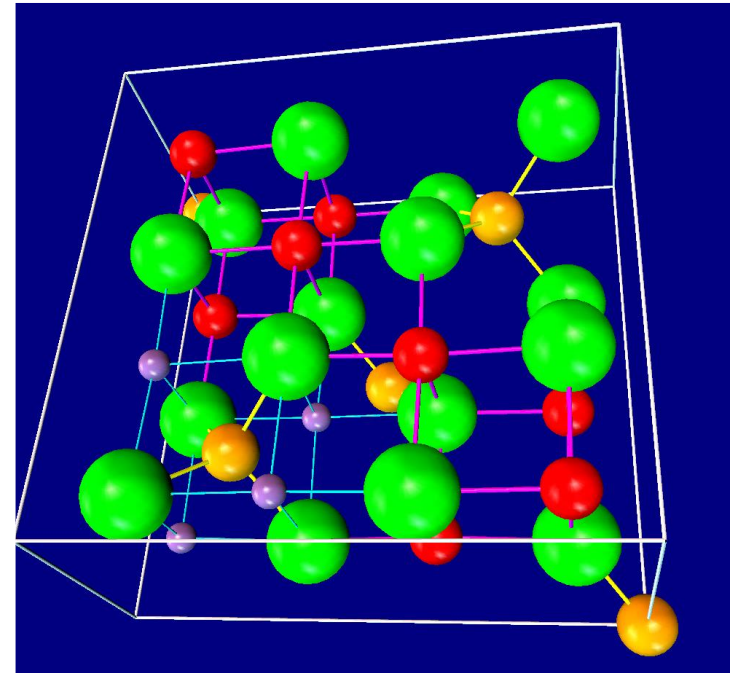
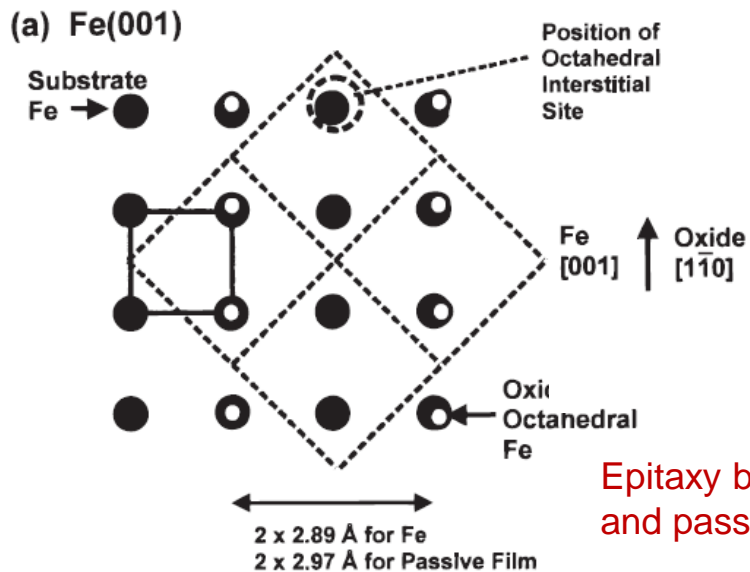
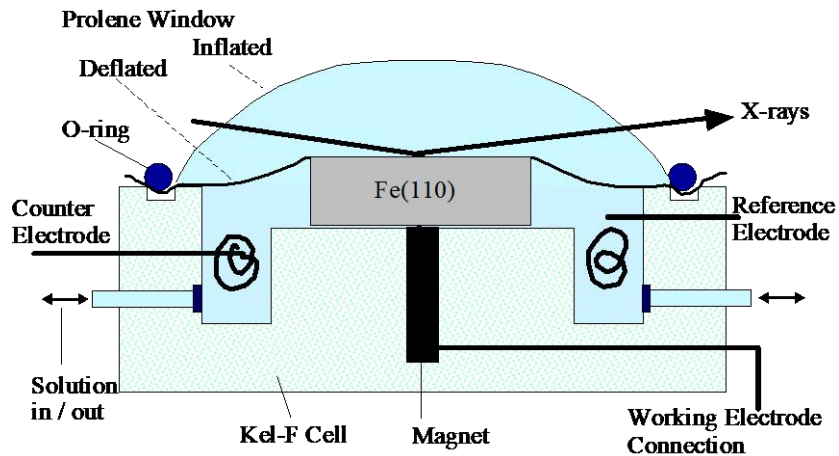
...unless you scratch the surface



Dissolution and passivation of magnesium

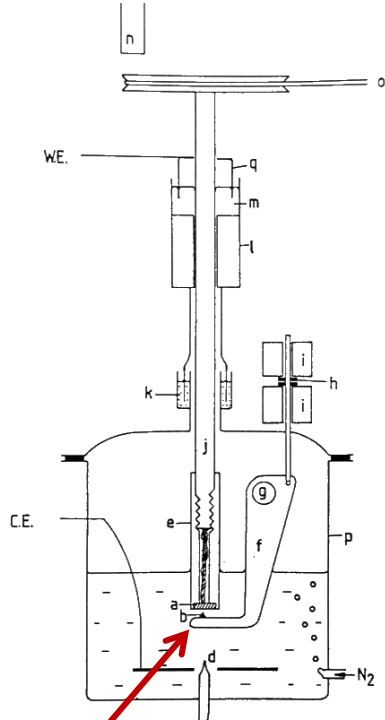


Structure of the passive film on iron

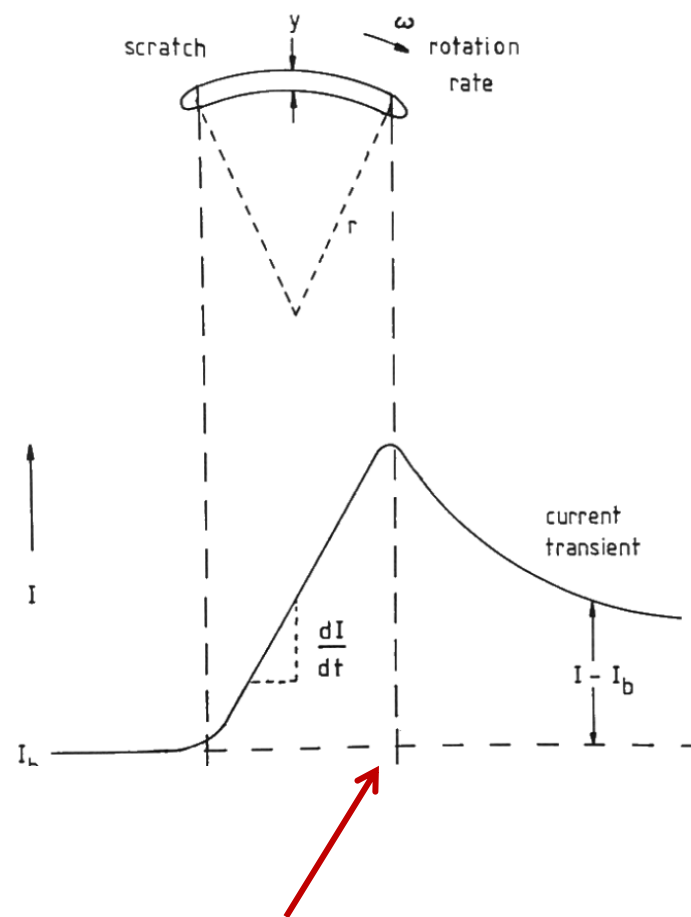


- 3-5 nm thick
- ~20 atomic layers thick
- spinel structure

M. F. Toney, A. J. Davenport, L. J. Oblonsky, M. P. Ryan and C. M. Vitus, "Atomic structure of the passive oxide film formed on iron" *Phys. Rev. Lett.*, **79**, 4282 (1997).

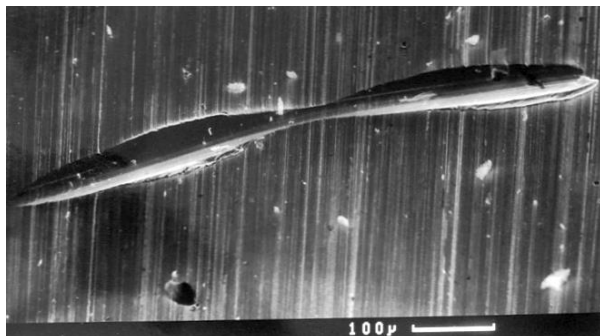


diamond stylus scratches rotating metal disc



burst of current as passive oxide film regrows in milliseconds

passive films grow very fast...



How fast can passive films grow?

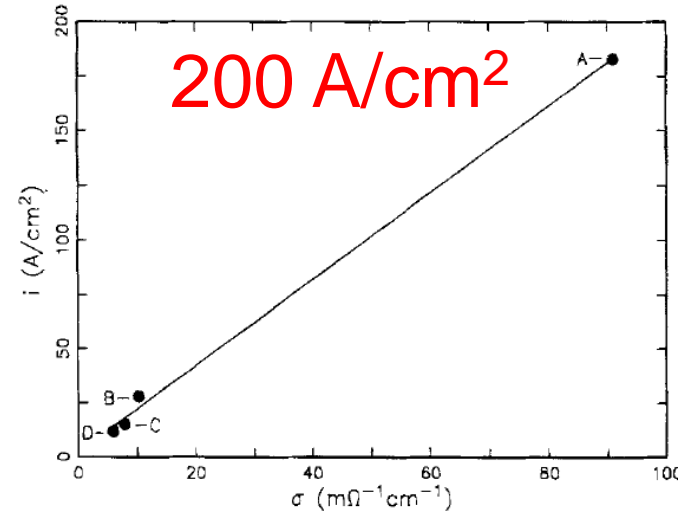
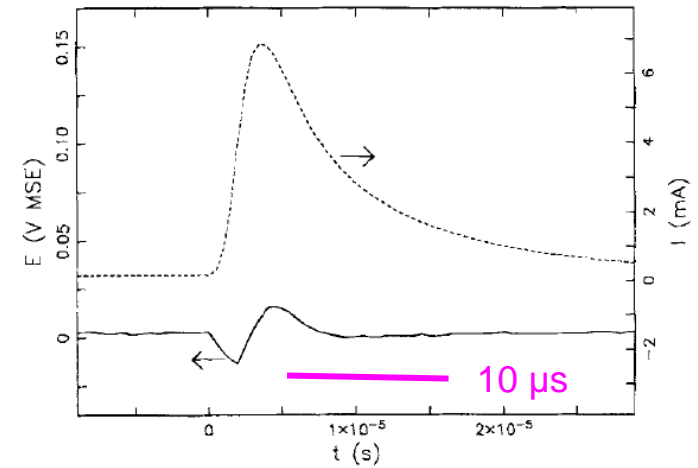
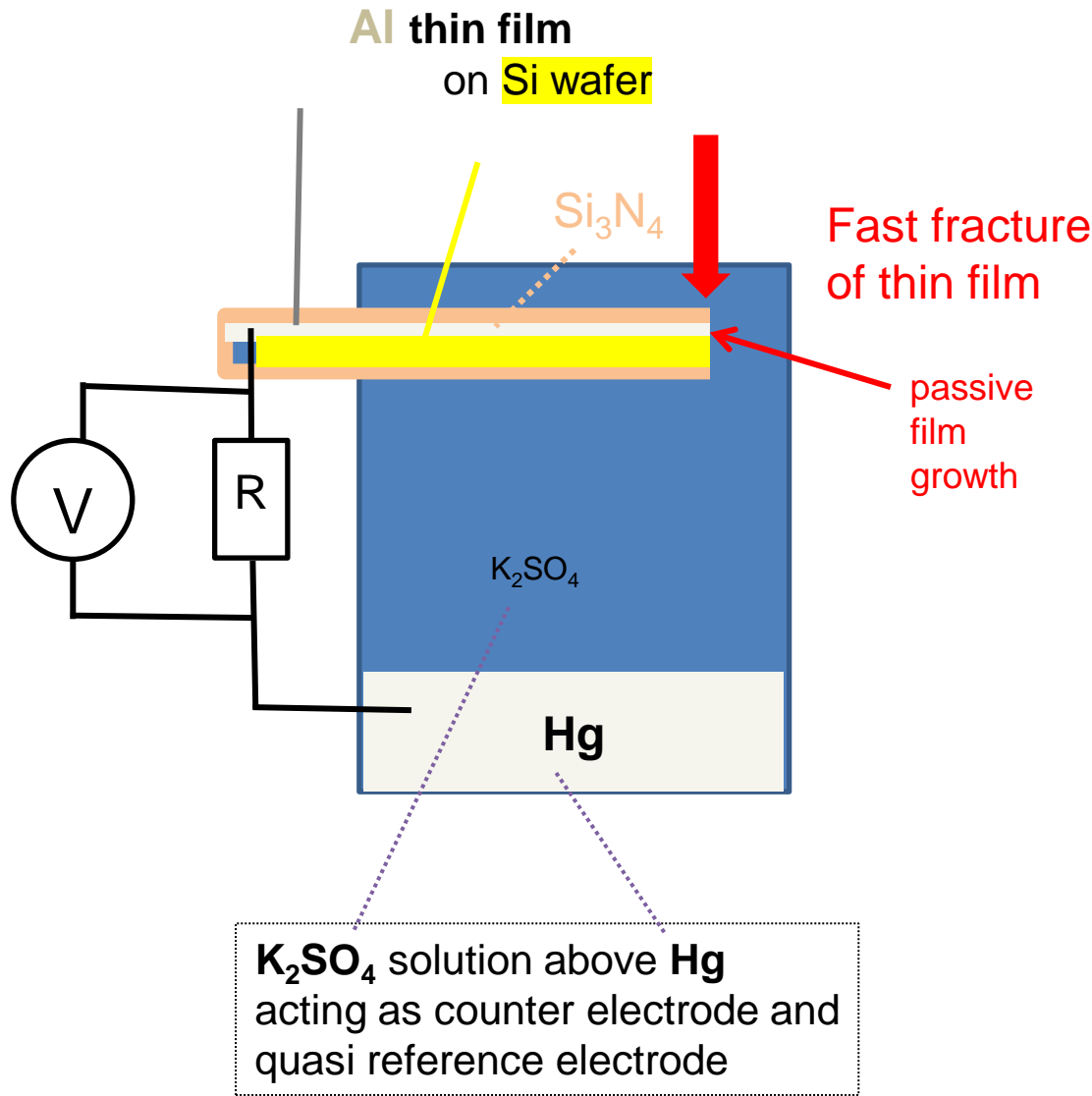


Fig. 4. Peak current density as a function of electrolyte conductivity for Al at -1.5 V MSE: (a) 1.2N K₂SO₄, pH 5.6; (b) 0.1N K₂SO₄, pH 12; (c) 0.1N Na₃PO₄, pH 9.2; (d) 0.1N Na₂B₄O₇, pH 9.2.

localised corrosion of Al airframes



localised corrosion
can lead to initiation
of fatigue in ageing
aircraft

Aloha flight, 1988



need to predict corrosion
propagation to determine
safe maintenance intervals

corrosion prediction
models generally assume
that corrosion is a slow and
steady process...



4-28-1988 After 89,090 flight cycles on a 737-200, metal fatigue lets the top go in flight.

atmospheric corrosion

salt deposits on metal surface
especially chloride



humidity increases, water droplet forms
on surface, forming salt solution



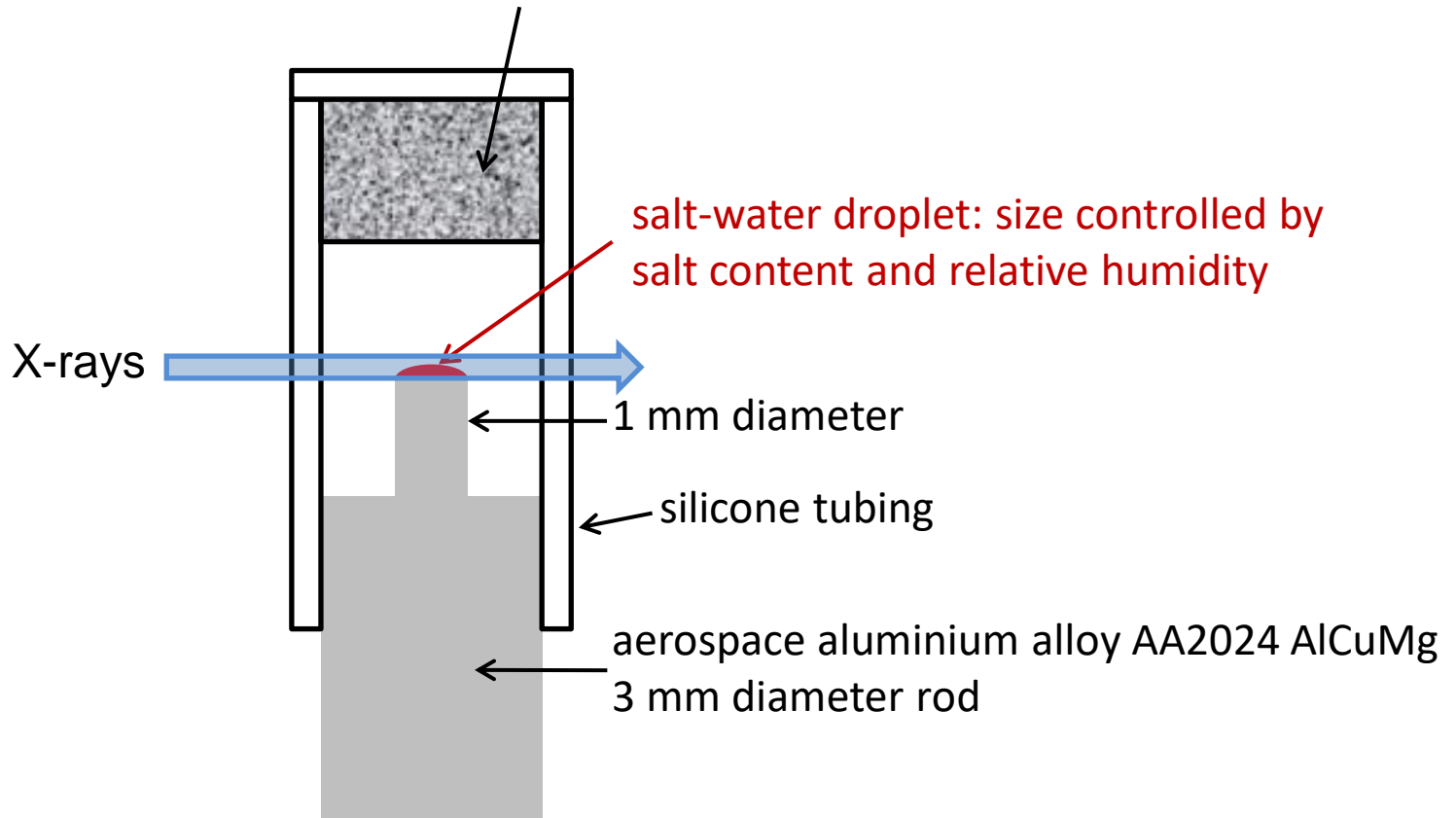
“deliquescence”

corrosion initiates in the droplet



Imaging atmospheric corrosion of aluminium airframe alloy AA2024

filter paper saturated with salt solution in equilibrium with salt crystals to **control relative humidity**



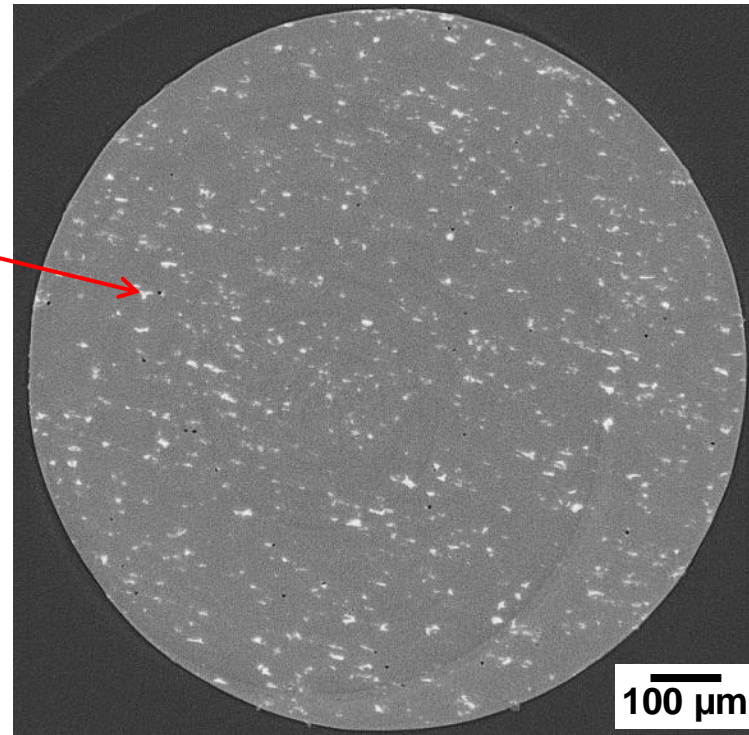
Tomography of Atmospheric Corrosion

Full rotation of pin to form 3D image in 5 minutes

Continuous measurement of corrosion in simulated seawater

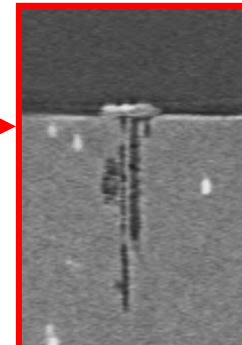
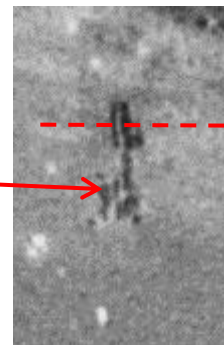
horizontal section through aluminium pin

iron- and copper-rich particles



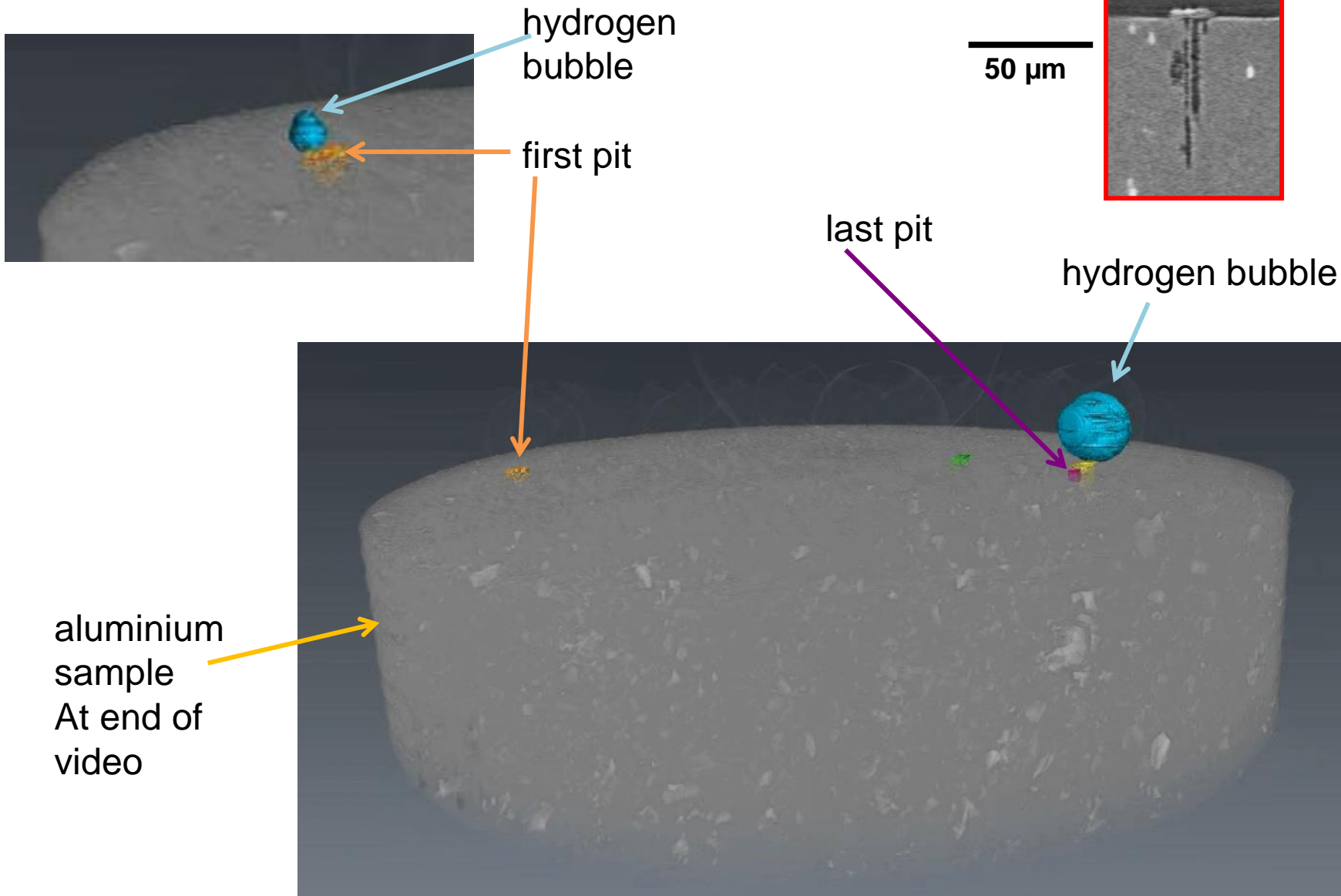
horizontal section vertical section

...horizontal and vertical sections through corrosion pits

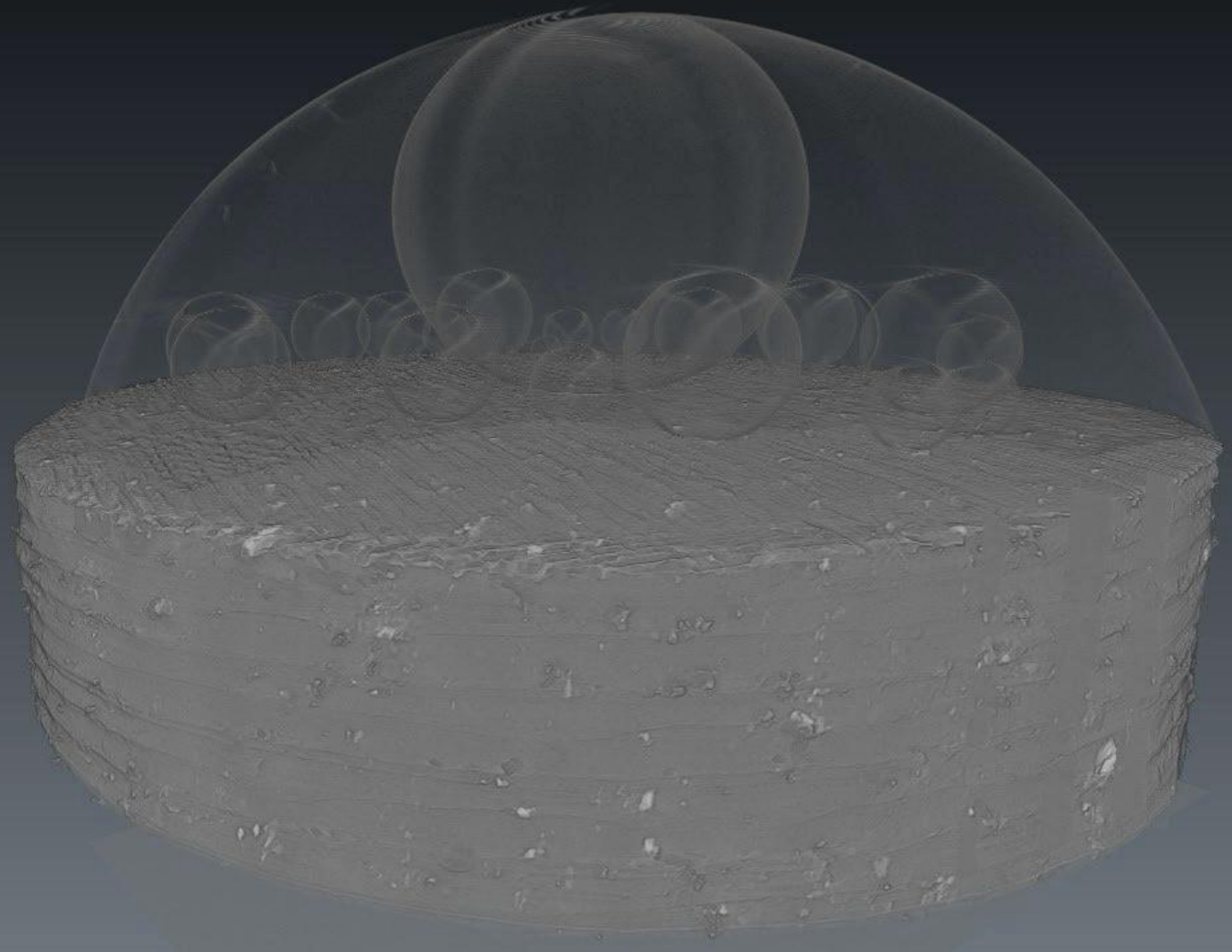


50 µm

3D “rendering” of data in a video



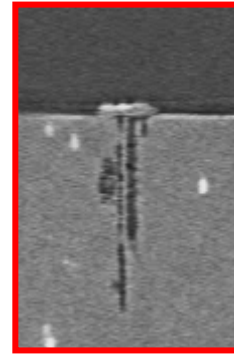
70 minutes



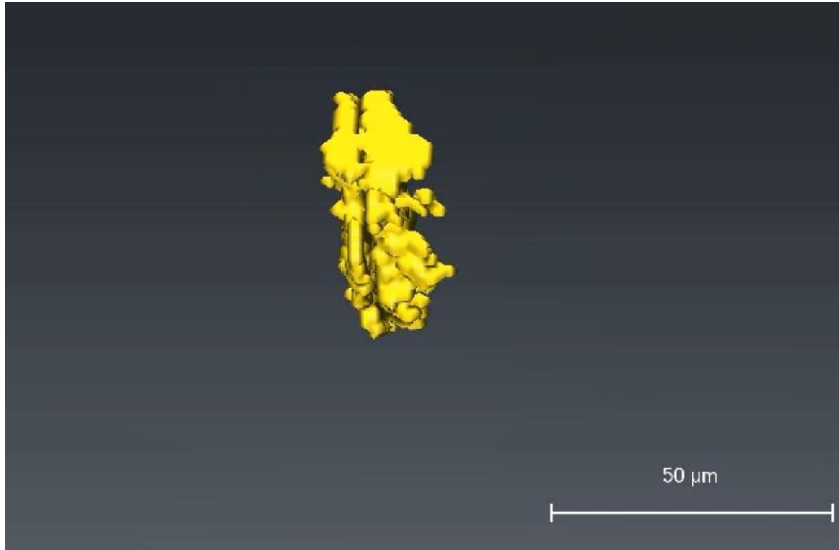
- largest pit through successive tomograms

- Red regions show additional corrosion in 5 minute interval after the yellow image

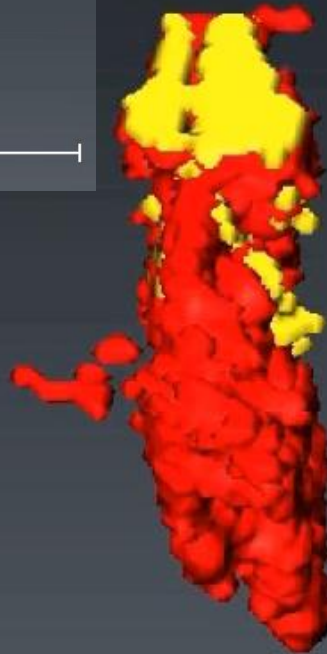
vertical section



50 μm

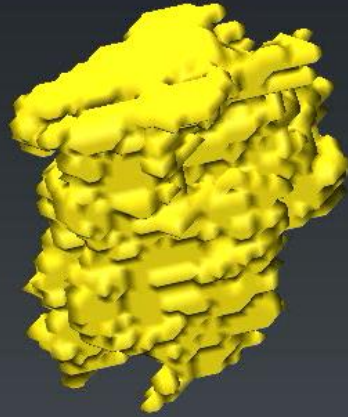


50 μm



50 μm

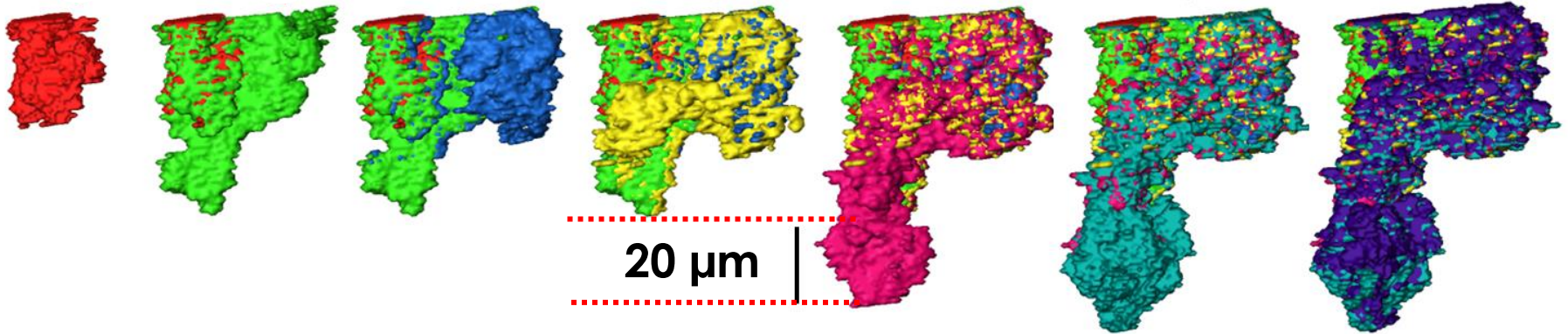
90 minutes



50 μm



how fast can aluminium corrode?



20 μm in 5 mins = *average* current density of **0.2 A/cm²**

6 mm in 1 day

4 cm in 1 week

>2 m in 1 year

....highlighting the challenges of developing corrosion prediction models where corrosion involves intermittent dissolution and passivation

Intermediate Level nuclear Waste (ILW) - stainless steel containers



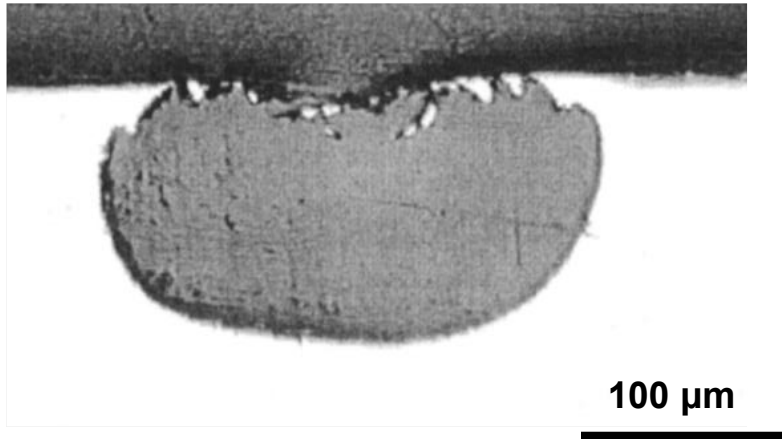
Currently in stores above ground

- UK does not yet have an underground storage facility
- pitting corrosion could lead to cracking
- no significant pitting seen yet...

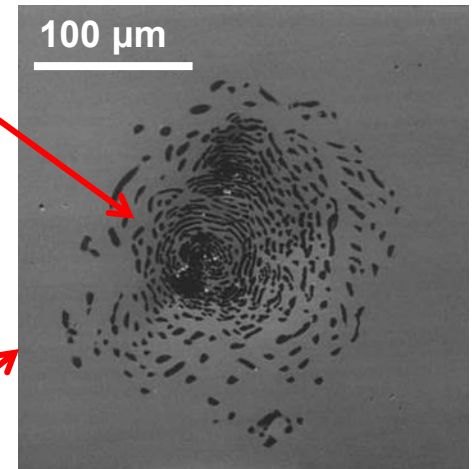
...but will it develop over >100 years?

pits in stainless steel fully immersed in water:

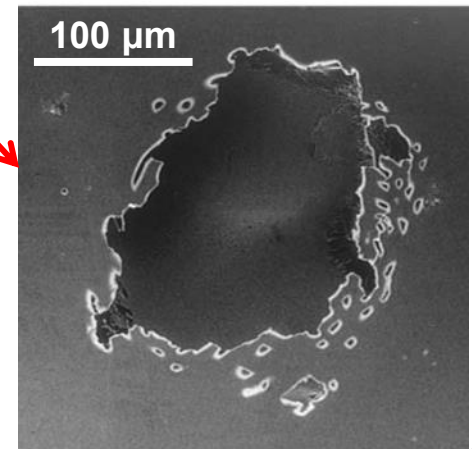
pits have perforated “lacy” covers
can we measure and
predict how these form?



Laycock and Newman



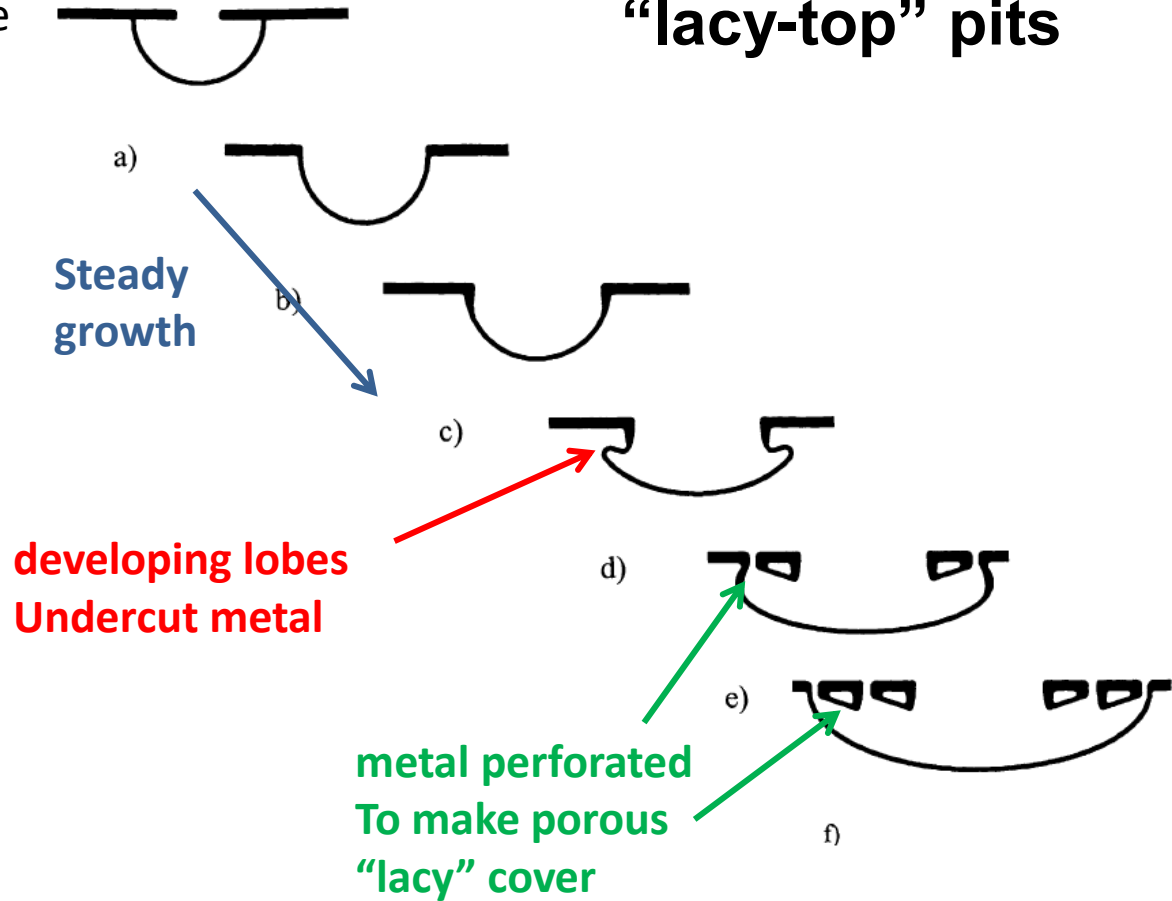
- lacy cover
- removed by ultrasonic cleaning to reveal pit



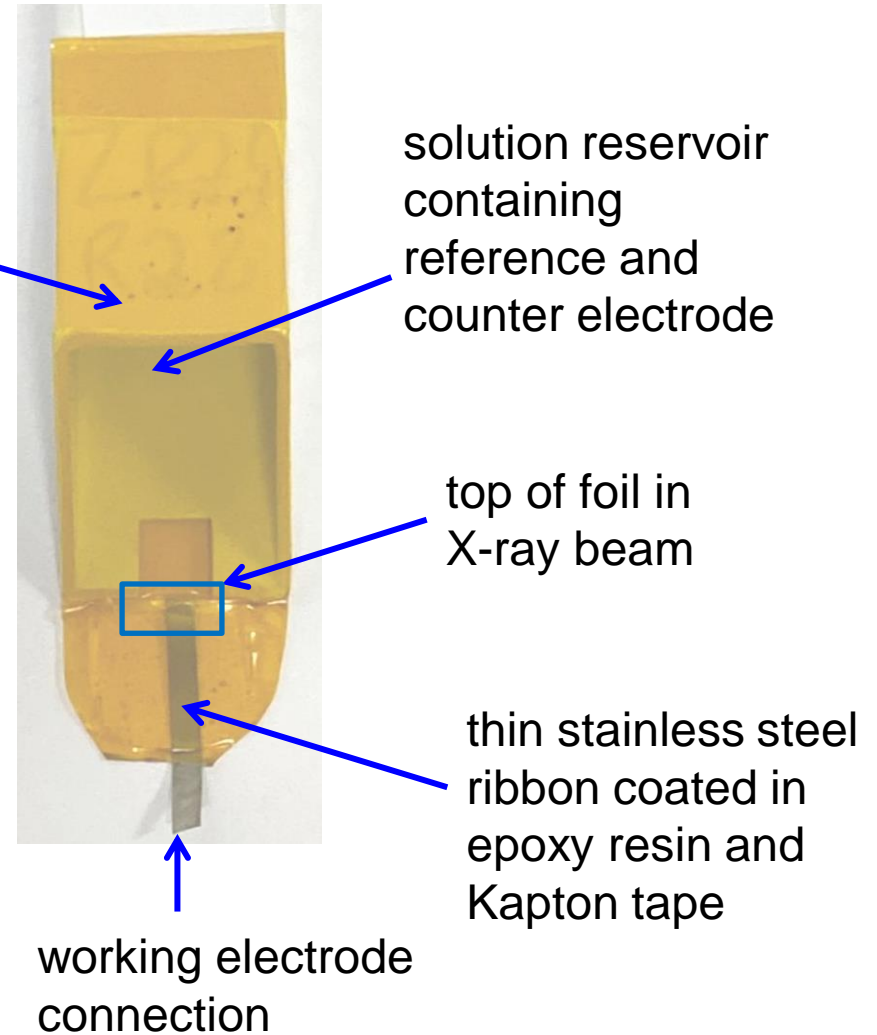
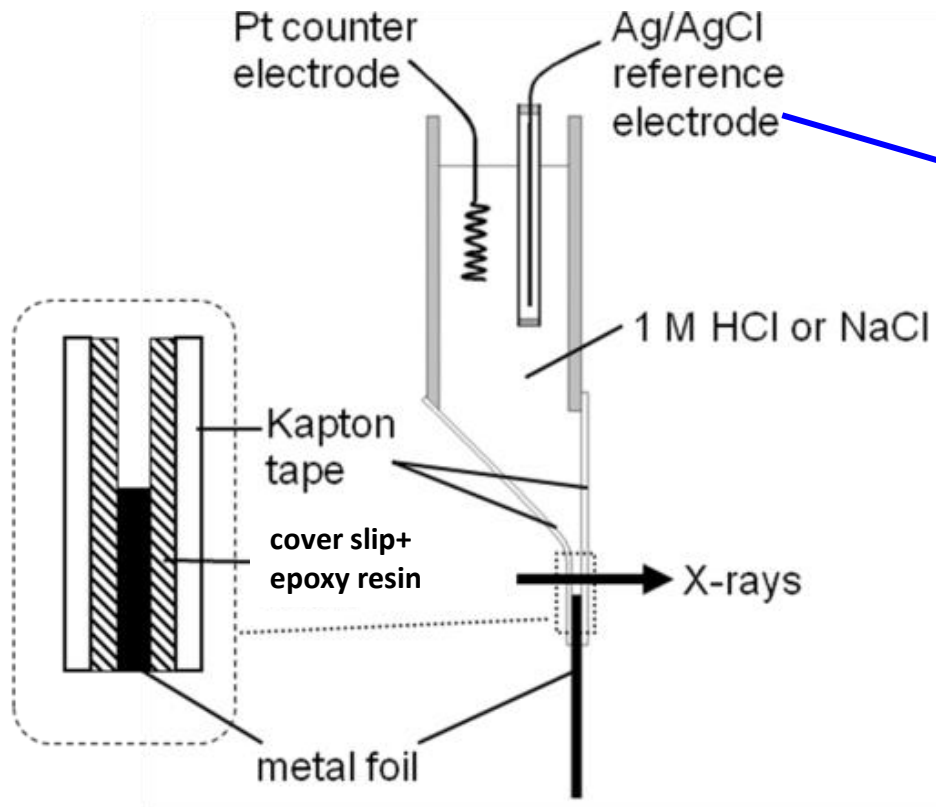
model proposed for pit
shape and lacy cover
formation based upon the
variation of the metal
cation concentration
inside the pit

P. Ernst and R. C. Newman
Corros. Sci., **44**, 927 (2002)

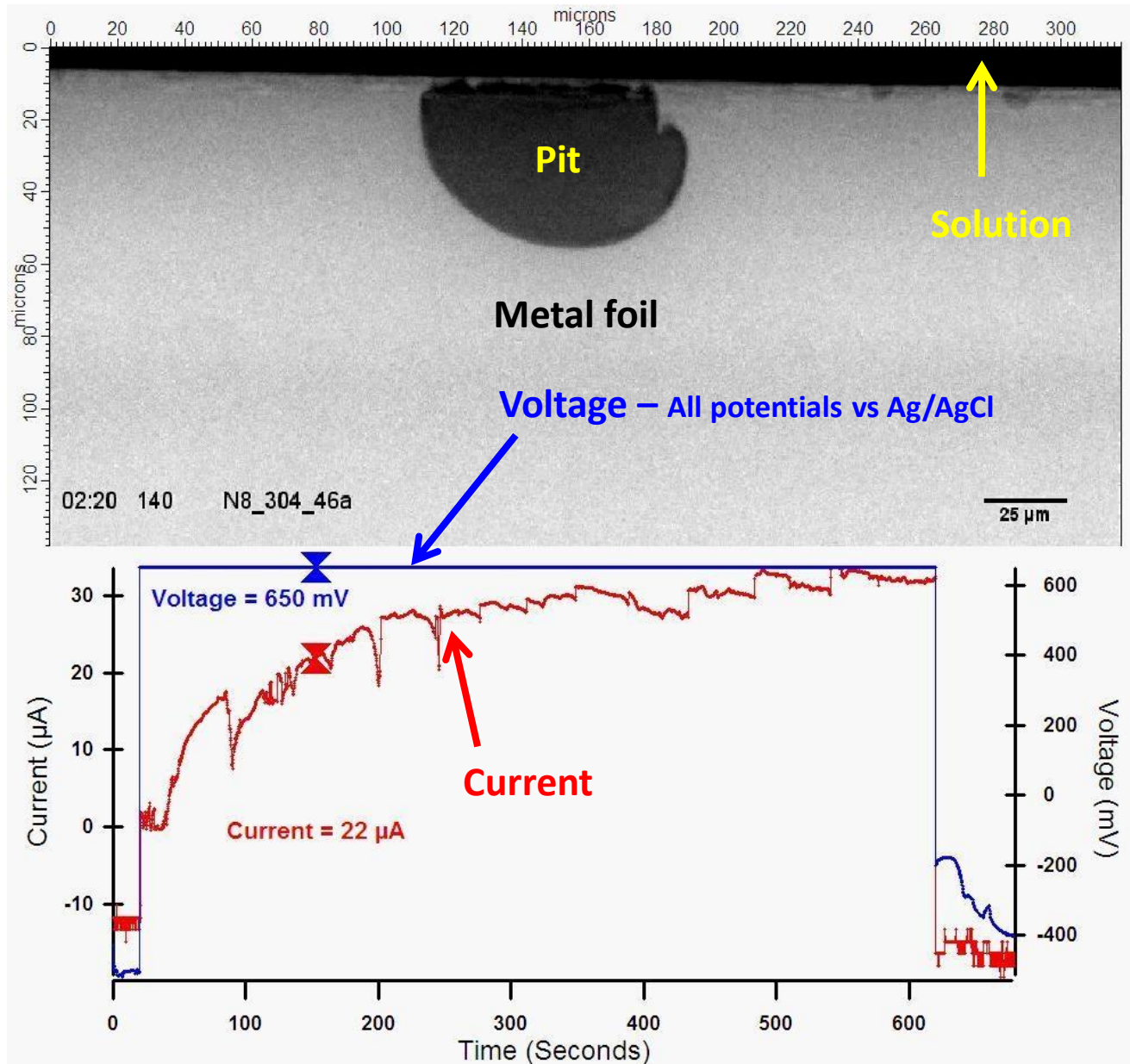
Mechanism of formation of “lacy-top” pits



Synchrotron X-ray Radiography of **2D pits**



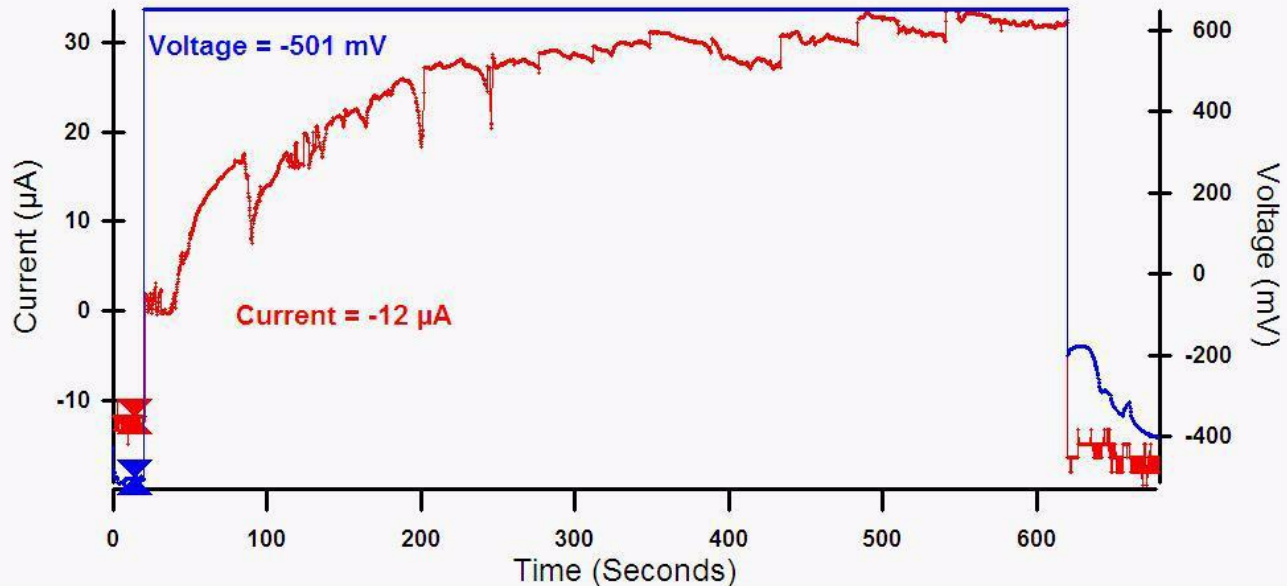
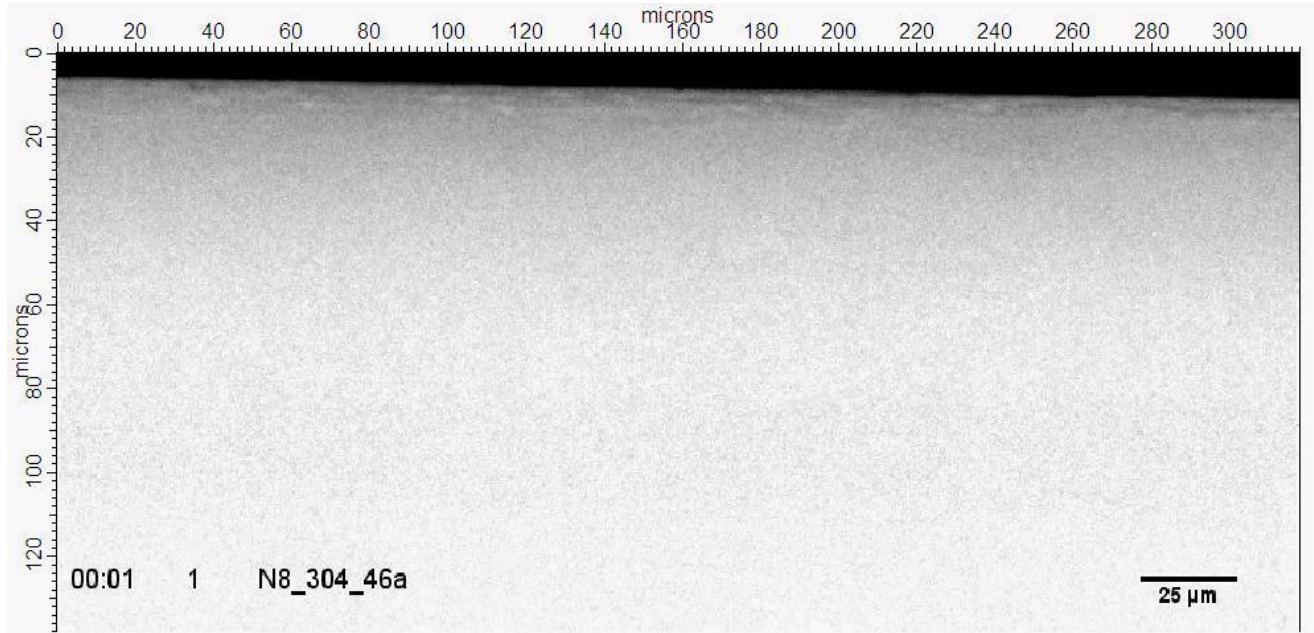
In situ 2D pit synchrotron X-ray radiography



Potentiostatic growth/ undercutting events

In situ 2D pit; synchrotron X-ray radiography

304 SS
0.005 M NaCl
650mV



Speeded up x40

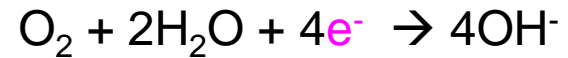
Pitting corrosion



cathodic reaction takes place outside pit

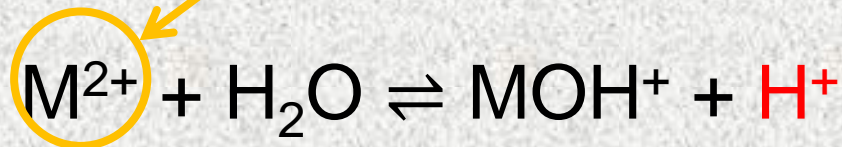
solution

Metal - M



concentrated
acidified
metal chloride

passive
film



metal ions react with water (**hydrolysis**)
to to make solution **acid**, which dissolves the
passive film

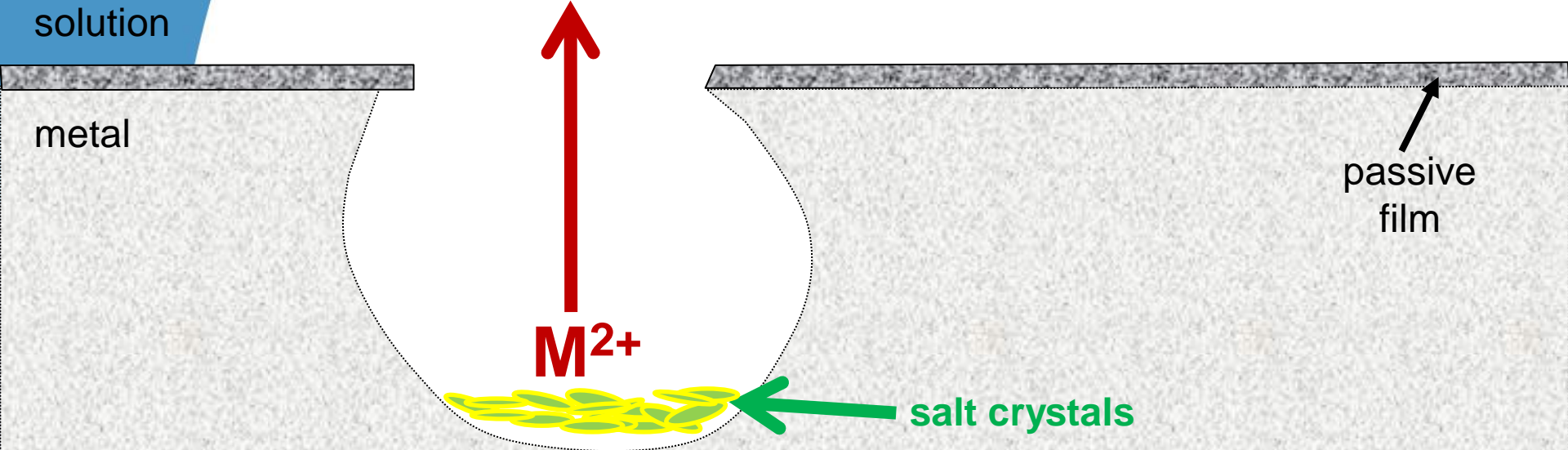
If **metal ions M^{2+}** are produced in the pit faster than they can escape by **diffusion**...

.....they will supersaturate and form a **layer of salt crystals** on the bottom of the pit



**INSTITUTE OF
CORROSION**

pitting corrosion



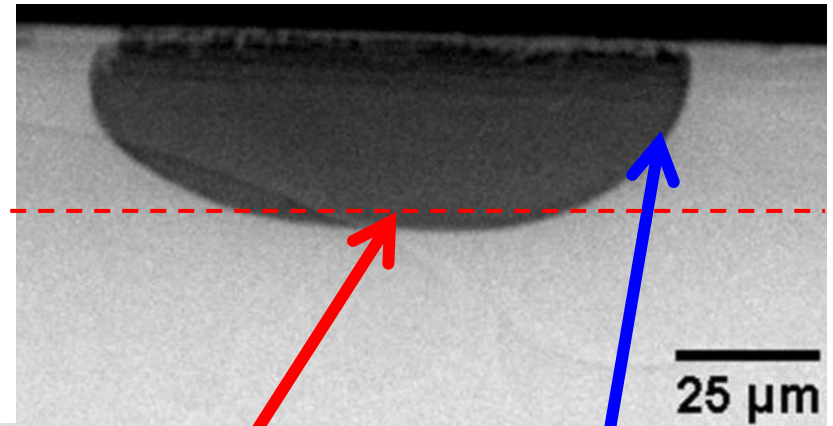
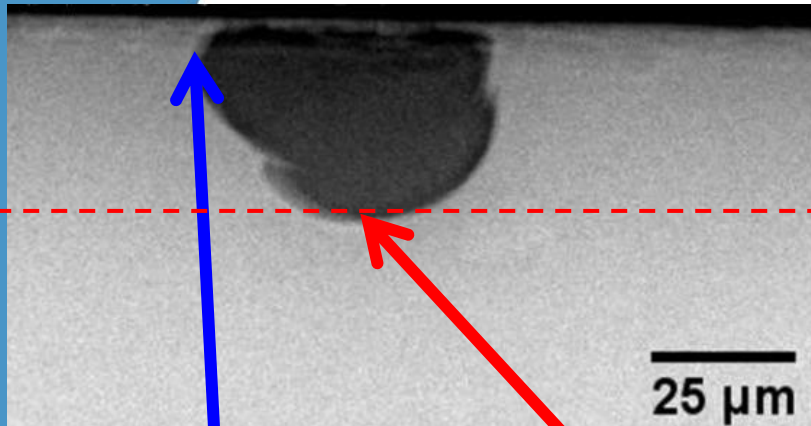
The **layer of salt crystals** will provide a resistance drop limiting dissolution of the pit bottom to the **diffusion-limited rate**.

Pit **depth** is limited by metal ion diffusion
– independent of bulk **solution concentration**

5 mM NaCl

growth for 60 s

100 mM NaCl



same depth – diffusion-controlled

solution concentration affects pit width

More concentrated solution has higher conductivity, so the interfacial potential is higher and the pit is wider

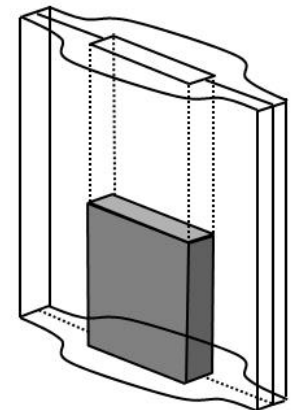
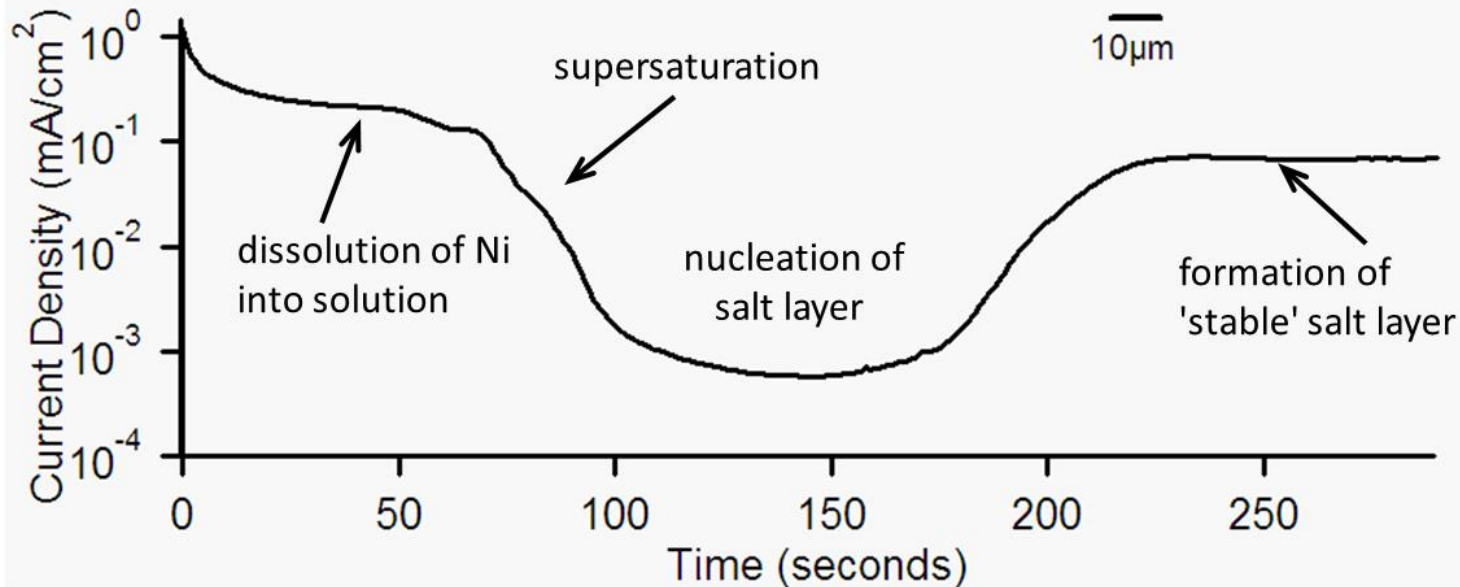
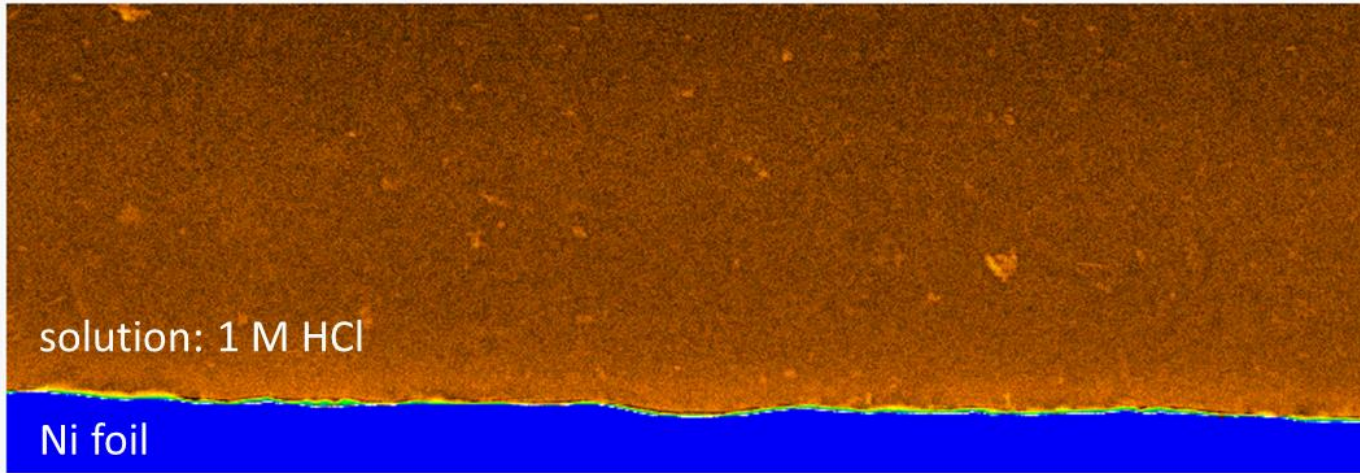
salt layers

X-ray radiography of Ni dissolution: 1D pits

Measurements at TOMCAT (SLS), 1s / frame, movie speeded x 10



350 nm
pixel size

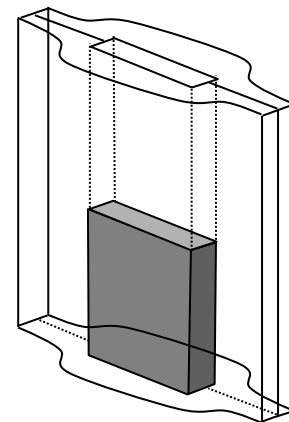
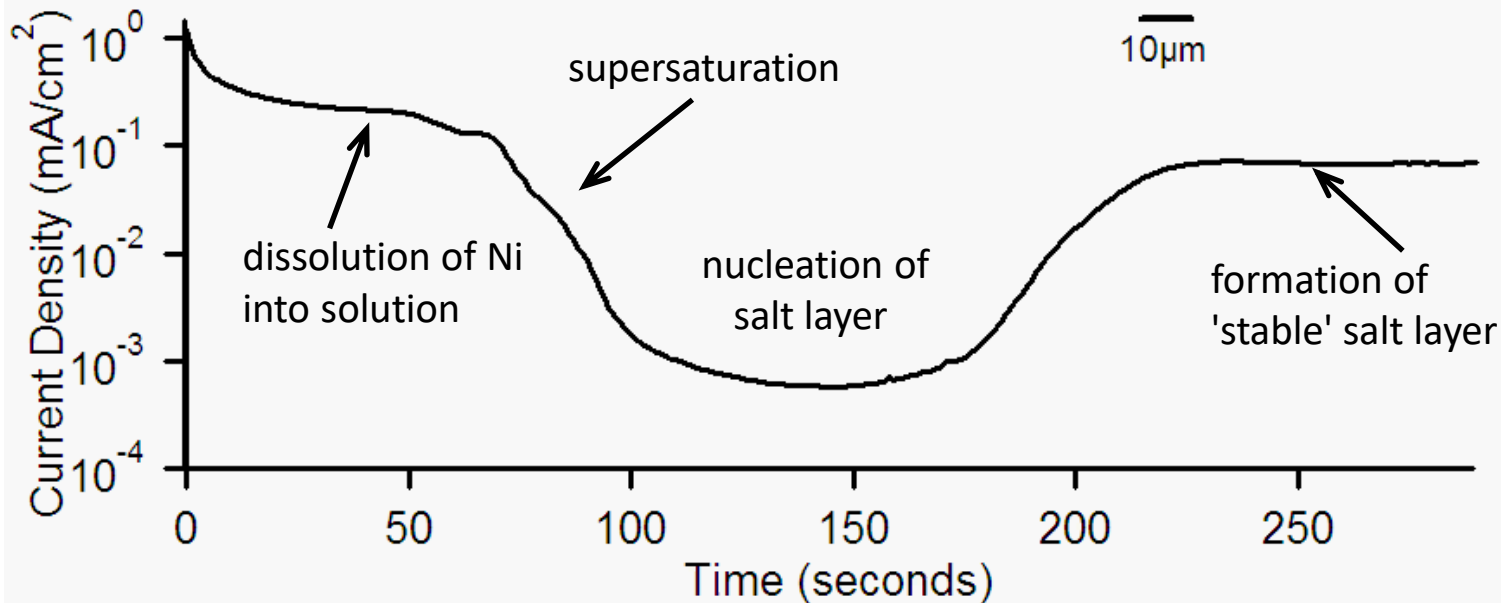
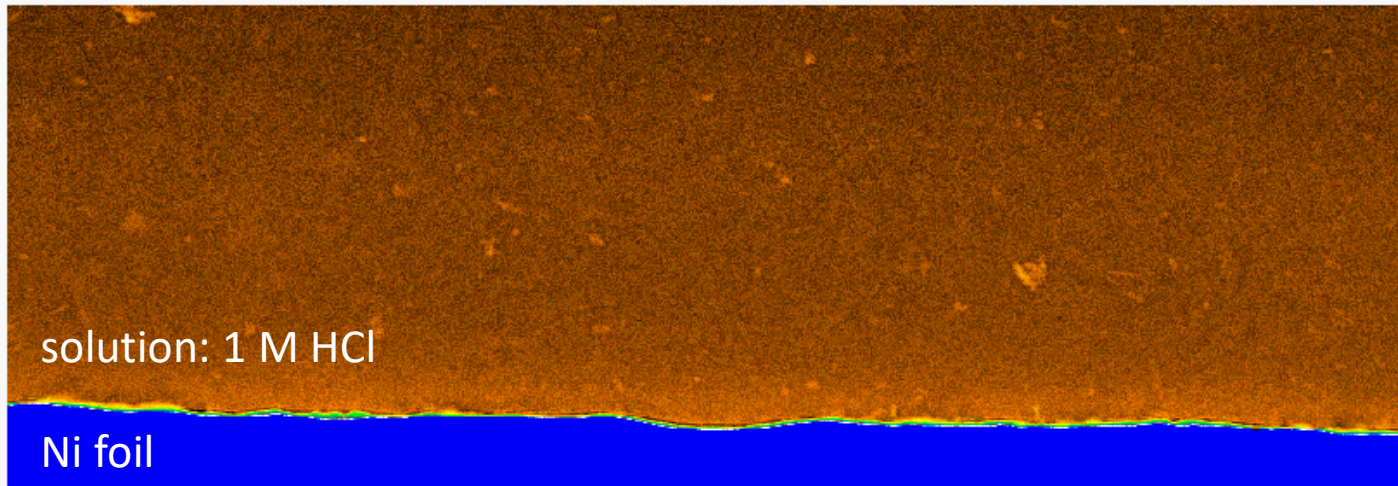


X-ray radiography of Ni dissolution: 1D pits



Measurements at TOMCAT (SLS), 1s / frame, movie speeded x 10

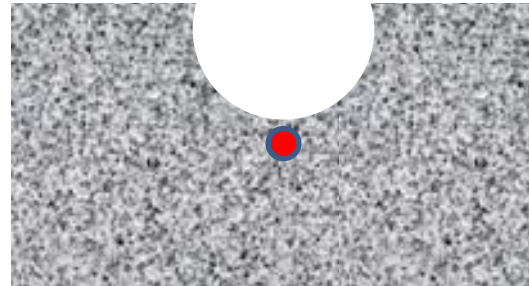
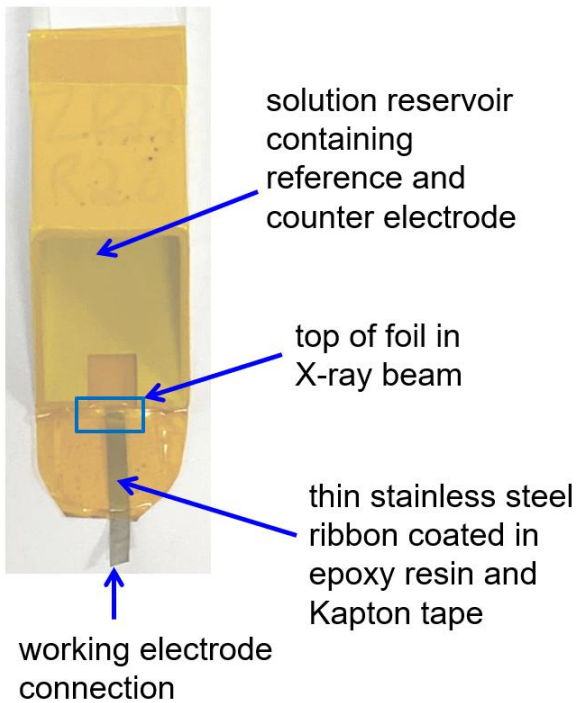
350 nm
pixel size



hunting for a salt layer In a growing pit

Top of foil with growing pit

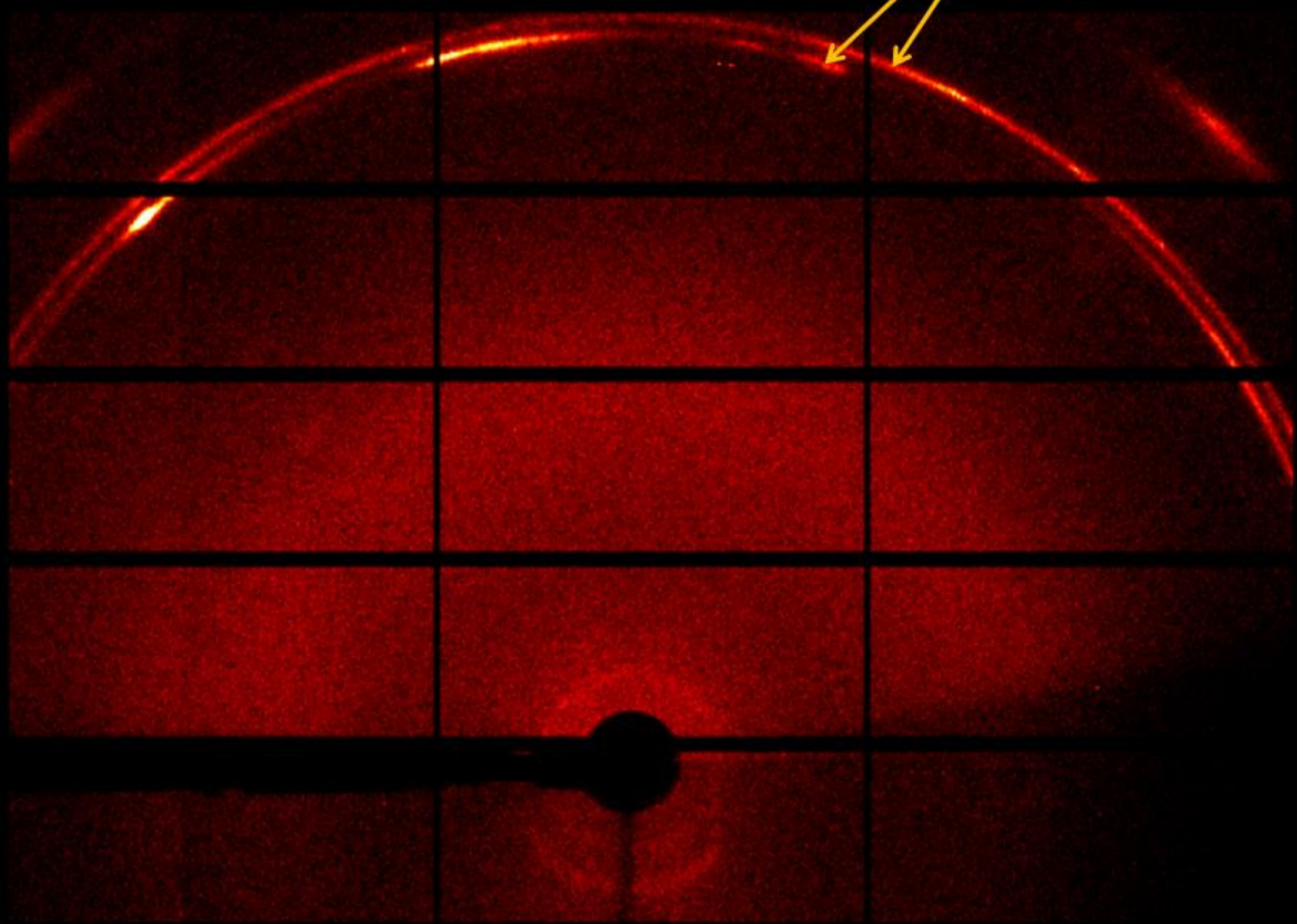
X-ray beam



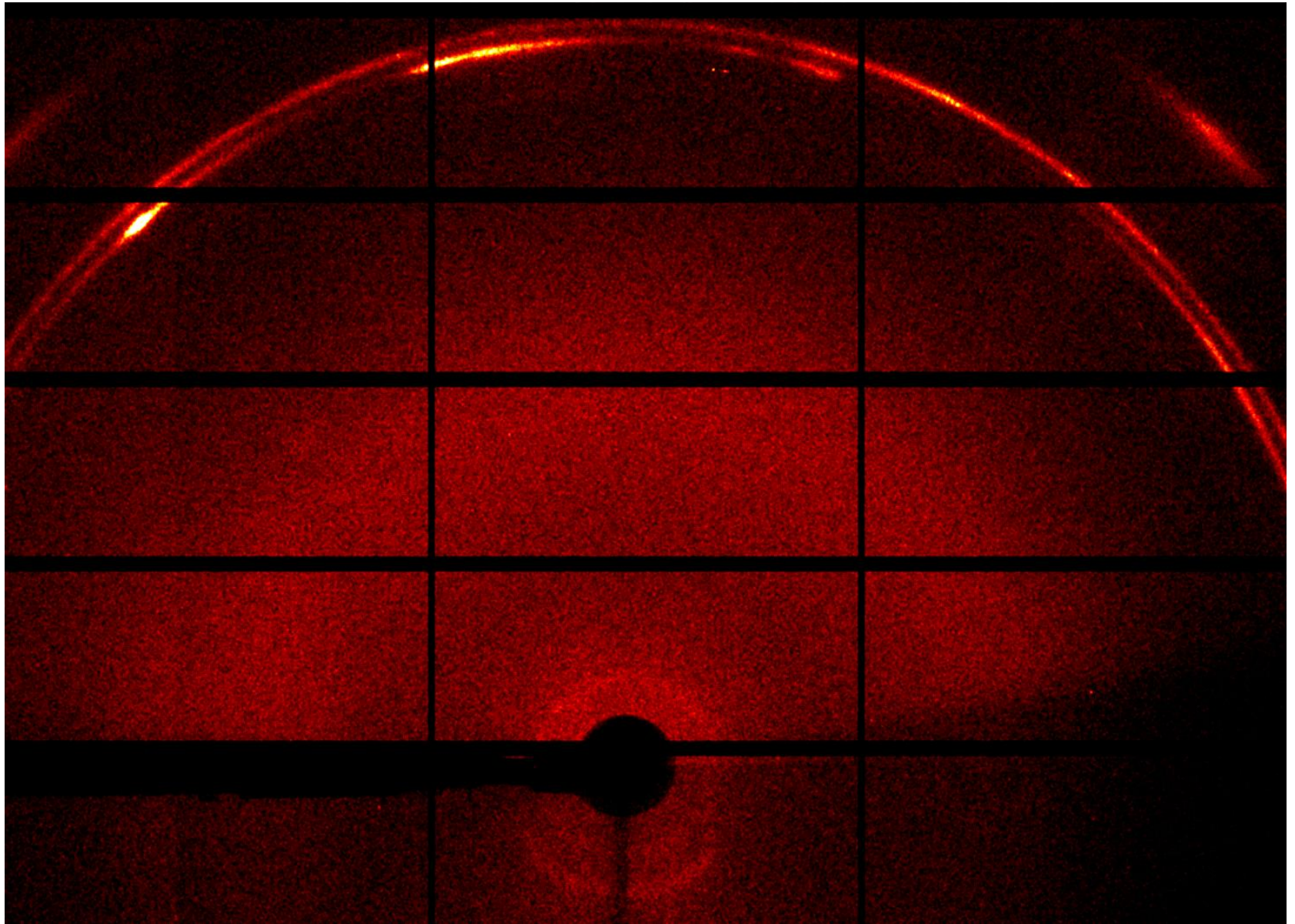
pit bottom grows through the beam

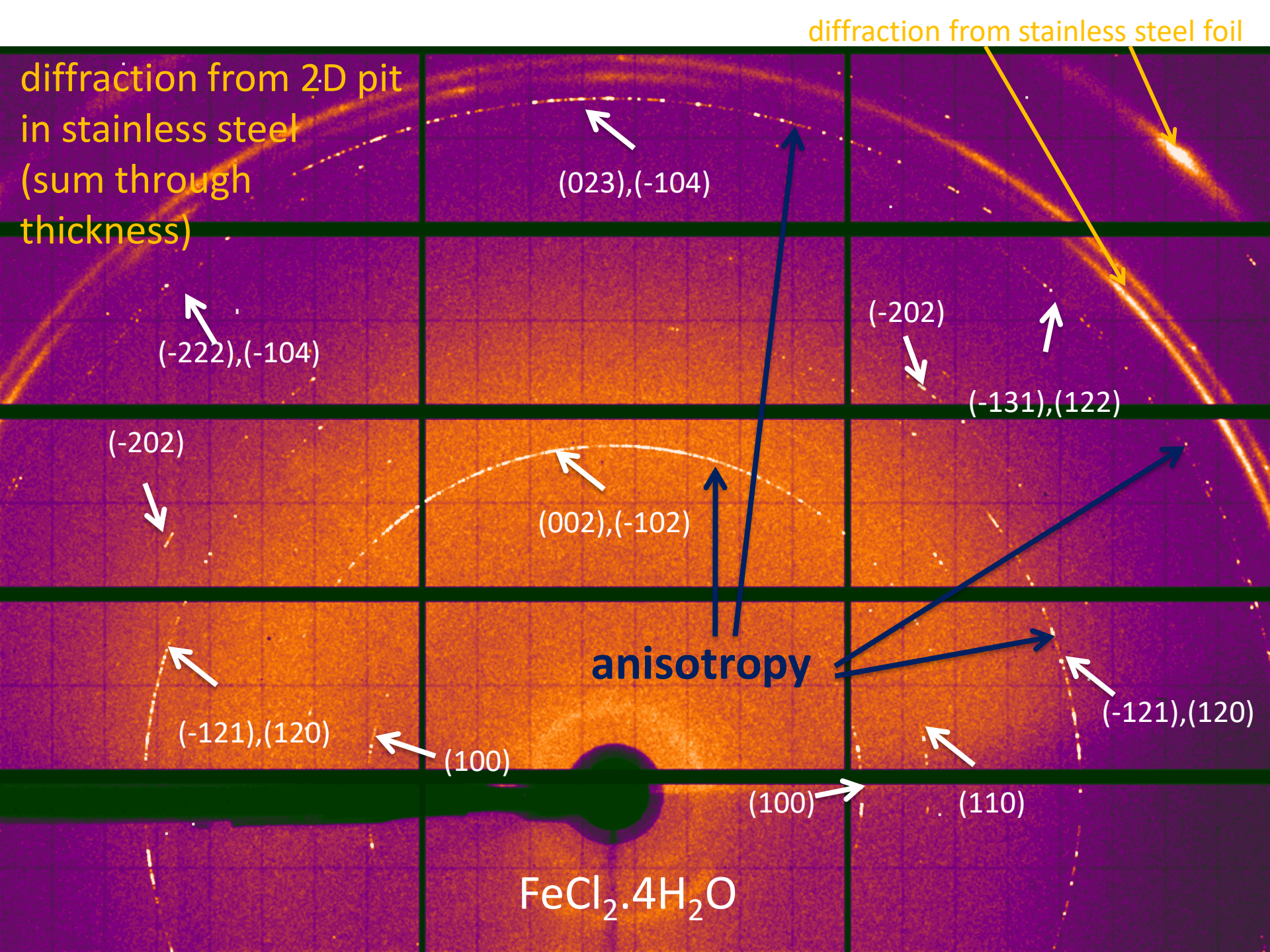
chasing pits

diffraction from
stainless steel foil

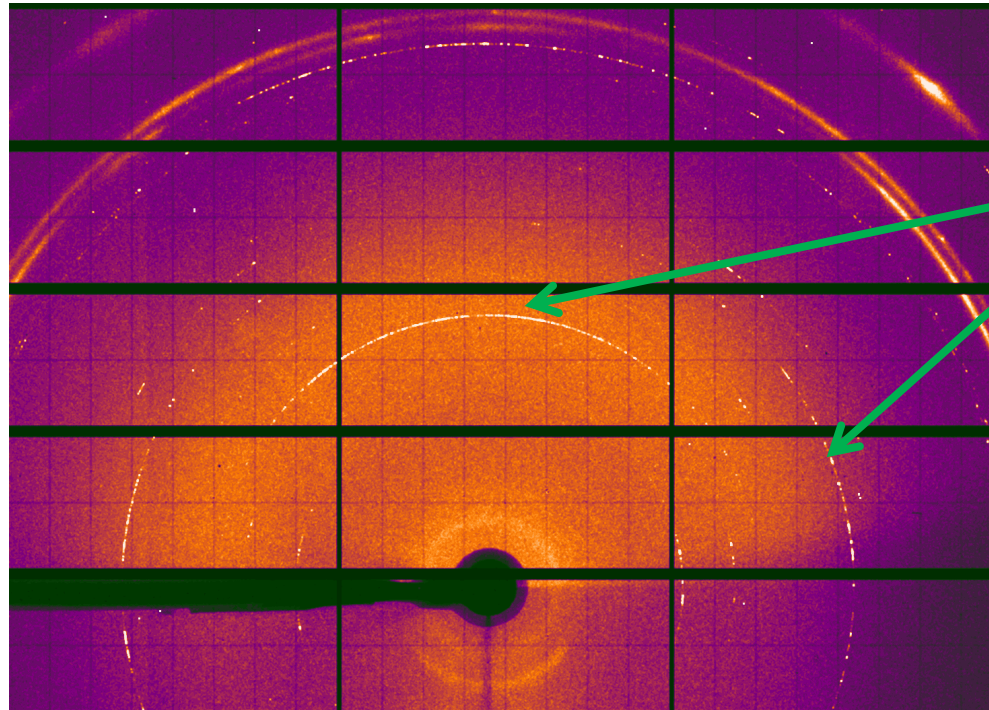


chasing pits





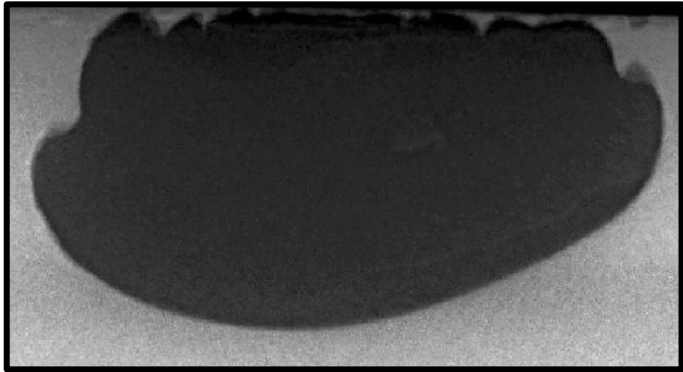
salt films in pits



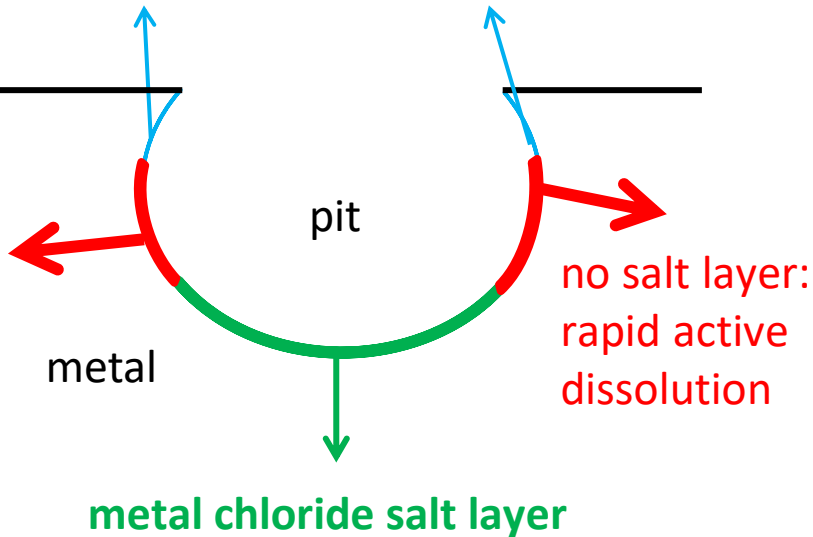
anisotropy

XRD evidence of textured salt film
controlling ion transport

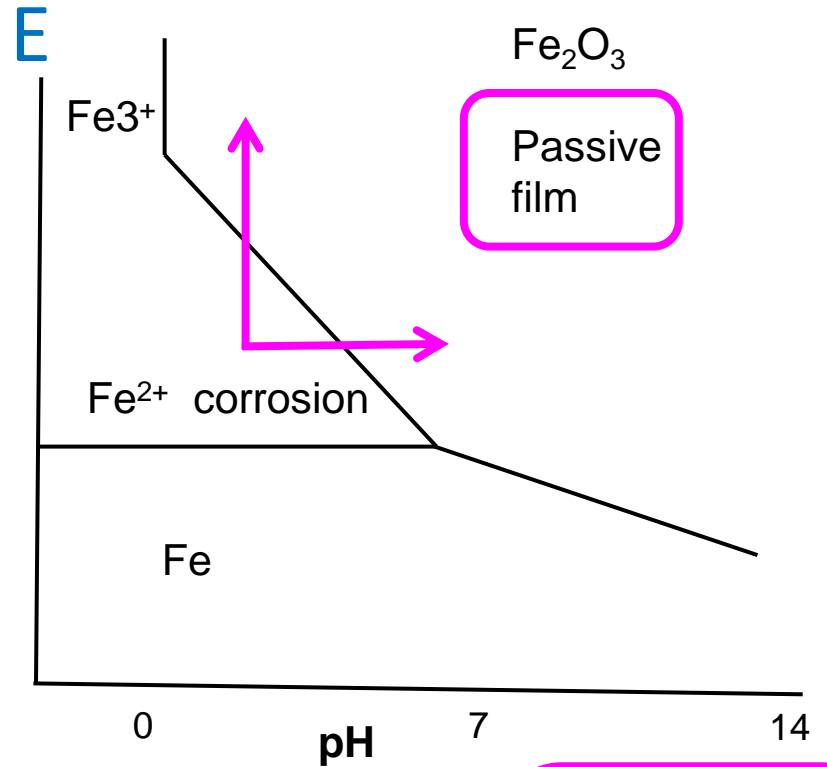




lower metal ion concentration leads to a **less acid** solution so the metal is **passive**



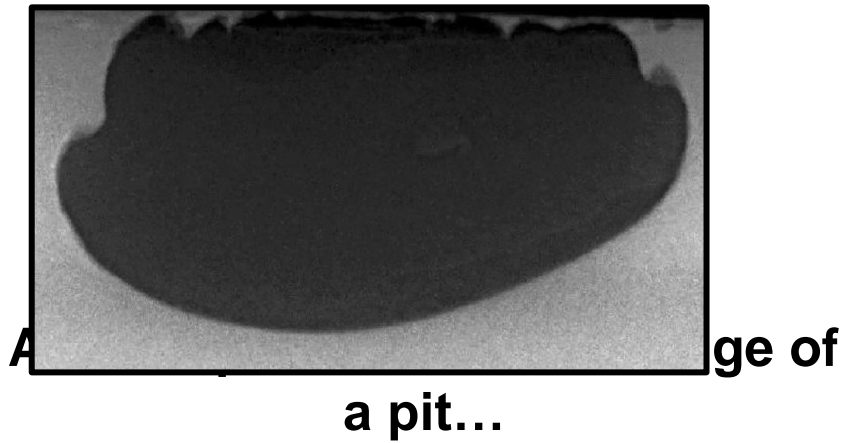
Pourbaix Diagram



HIGH
concentration
of metal ions
acidic

LOW
concentration
of metal ions
alkaline
passive

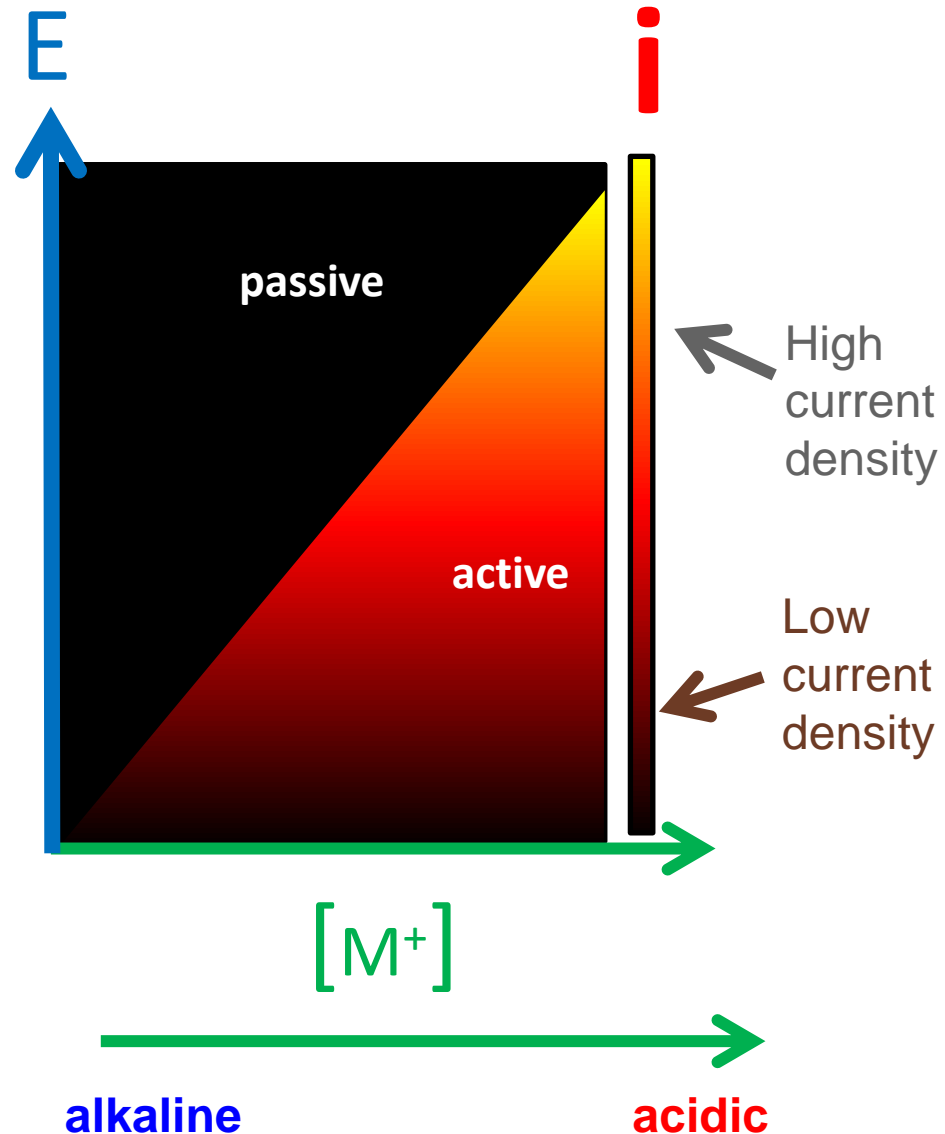
concentration of metal ions: $[M^+]$



Local current density i is a function of

local solution chemistry -
concentration of metal ions:
 $[M^+]$

and local interfacial potential E
... affected by iR drop in the pit



Competition between dissolution and passivation

Oxide film growth – high field kinetics

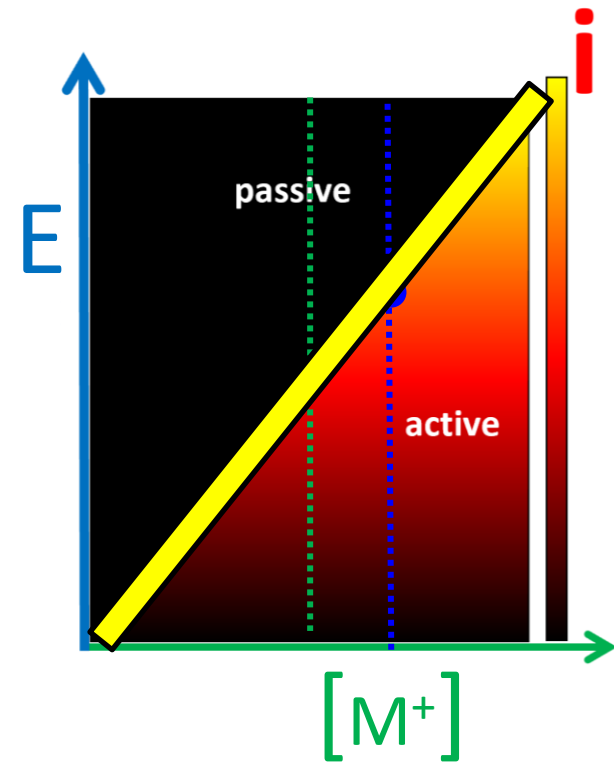
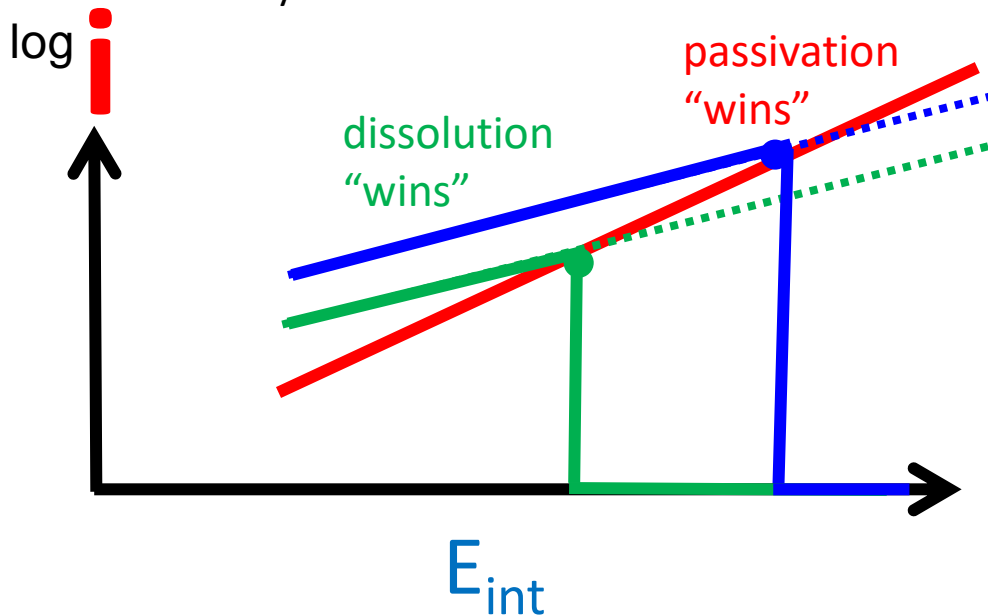
Anodic dissolution Tafel

...

Linear relationship between $\log i$ and E_{int}

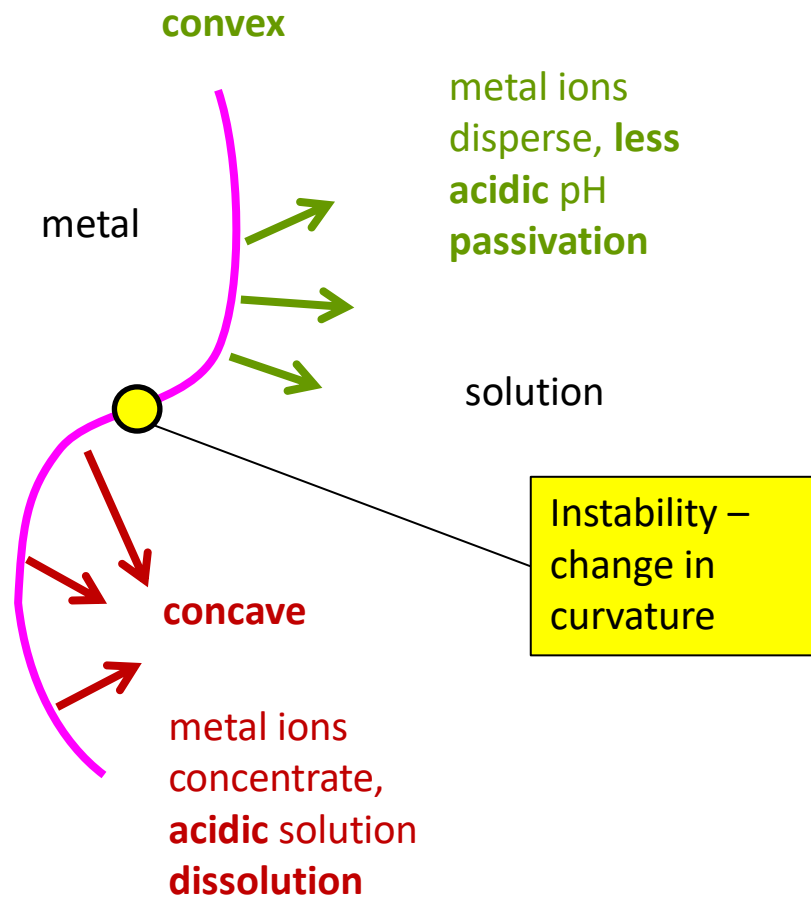
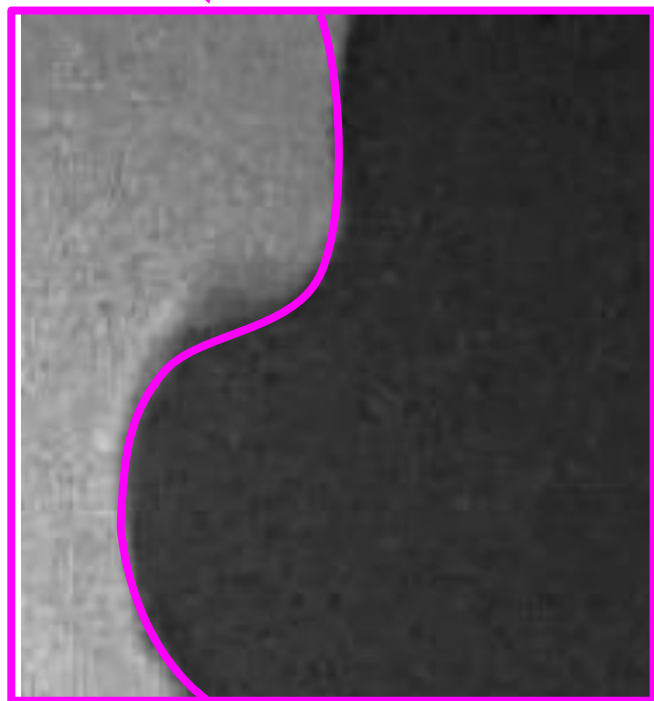
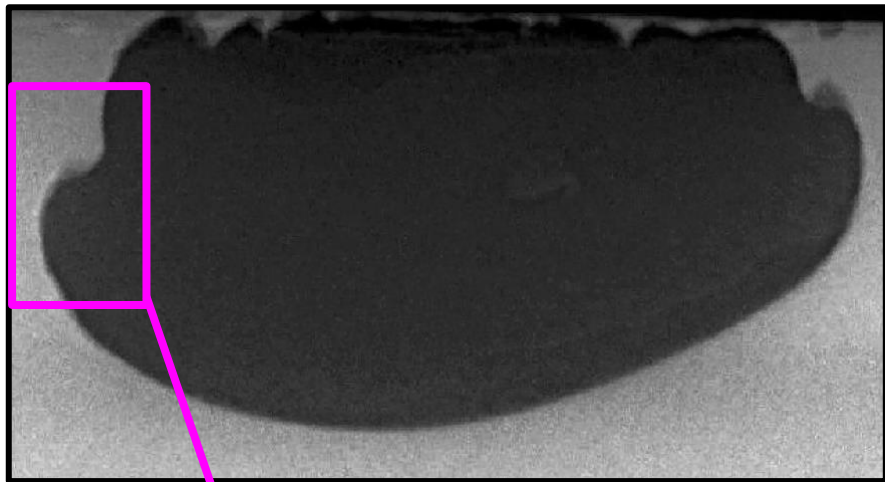
anodic dissolution continues until the rate of film growth is faster, when passivation occurs and current drops to very low level

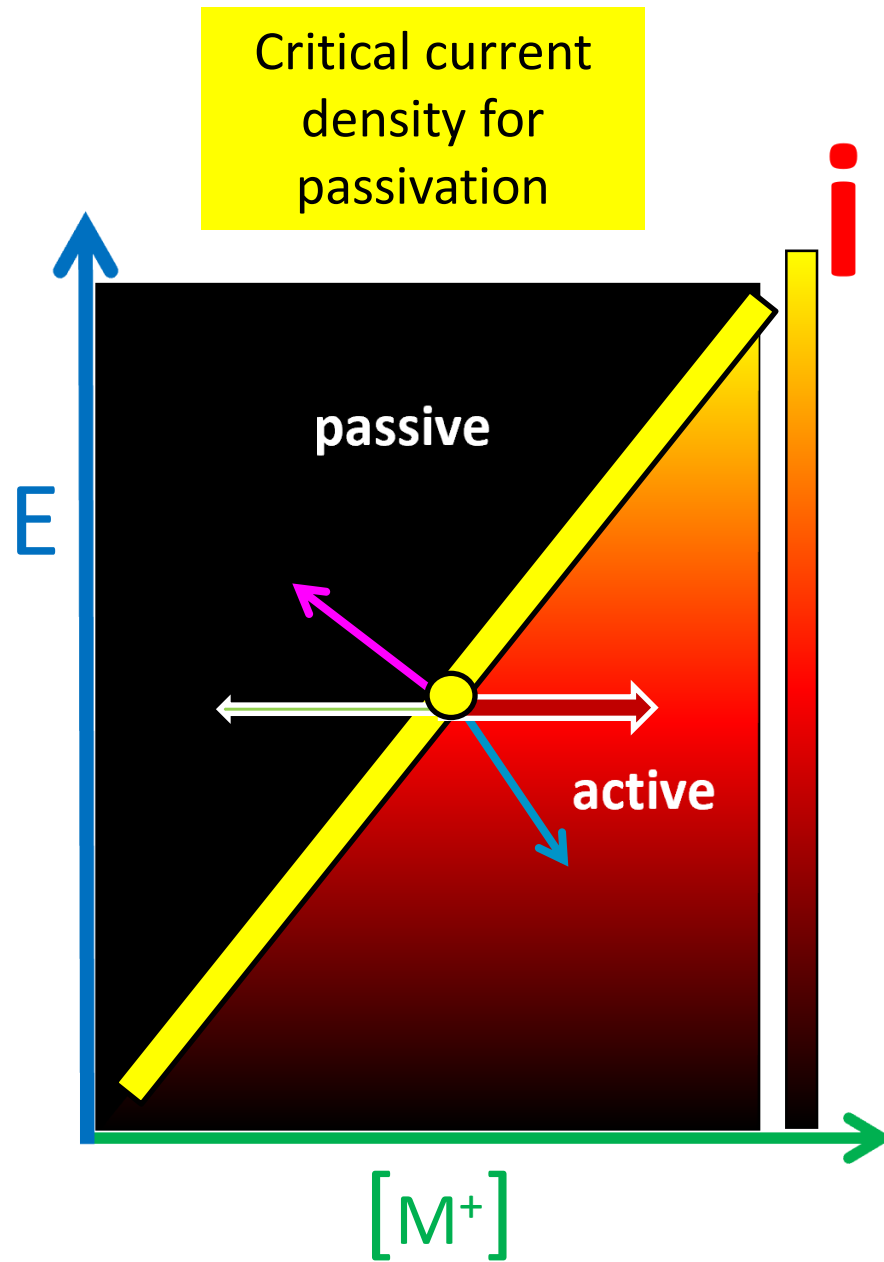
dissolution at higher $[M^{n+}]$



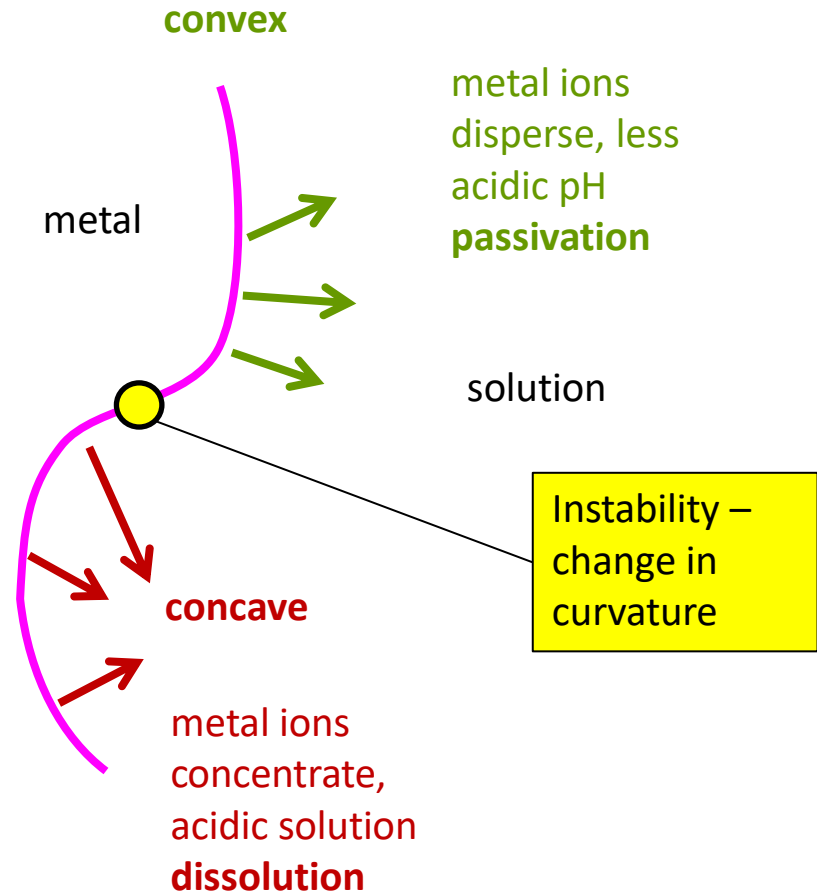
Critical current density for passivation

How do lobes develop?



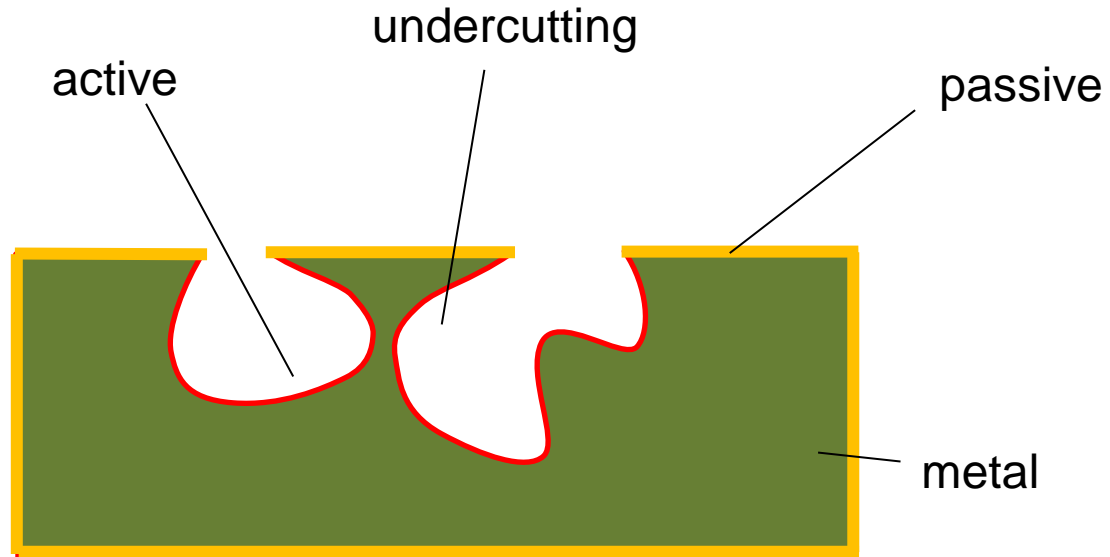


Close to pit mouth -
Interfacial potential higher

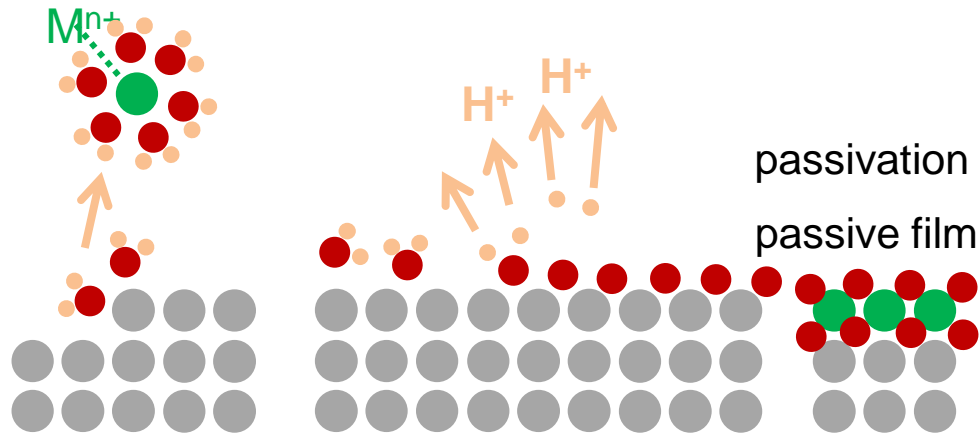


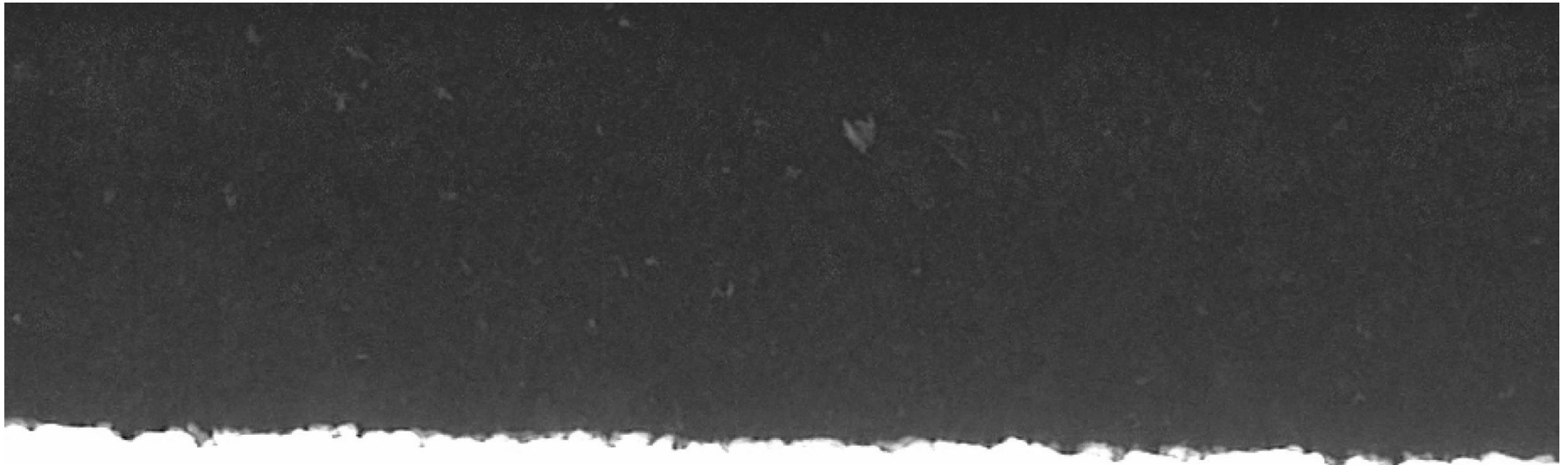
Deeper in pit -
Interfacial potential lower

DISSOLUTION vs. PASSIVATION



dissolution



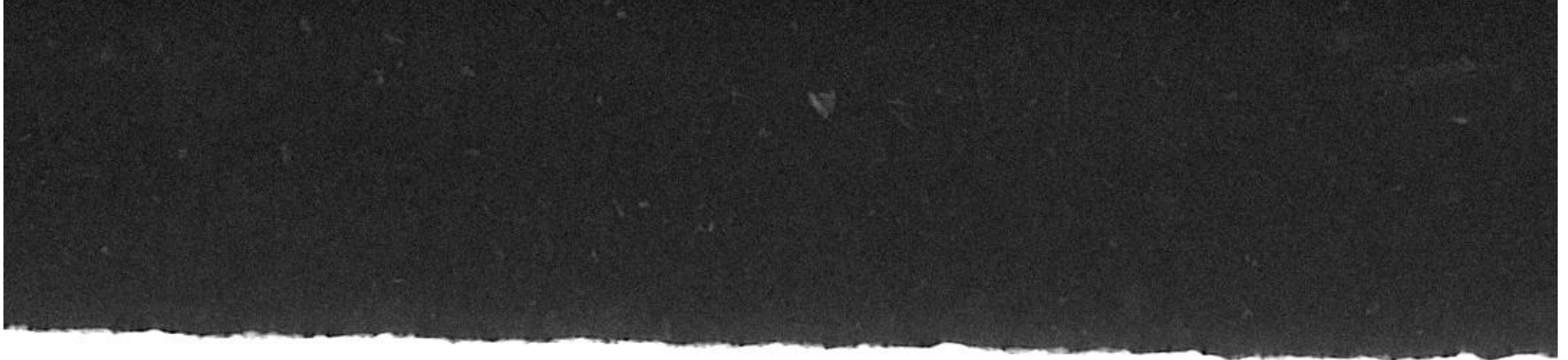


100 μm

Potentiodynamic polarisation of Ni in / 1 M HCl

Dissolution, roughening, salt layer formation

speed x40



—
100 μm

Potentiodynamic polarisation of Ni in / 1 M HCl
Dissolution, roughening, salt layer formation

speed x40

Paper 2 – Chris Lynch





Bio – Chris Lynch



Bio - Chris Lynch is the Senior Engineering Manager at Corpro Companies Europe Limited. His career started as a Graduate Corrosion Engineer at ACEL in Aberdeenshire in 1991 and has dedicated himself to a career mainly specialising in Cathodic Protection of Buried and Marine Structures in the UK, Offshore and Overseas. Chris is voluntarily active in training CP technicians and Engineers since the mid 90's for the Institute of Corrosion and currently Chair of the BSI Committee GEL/603 'Cathodic Protection'. He is an active and working group member and contributor to several institutions including CEOCOR, BS/CEN/ISO and The Marine Corrosion Forum. A Chartered Engineer, a Fellow Member of ICorr and an ISO Level 4 Competent person in Cathodic Protection of Buried, Marine and Internal Metallic Structures and a member of the Cathodic Protection Governing Body (CPGB) on behalf of Institute of Corrosion for training provision. He holds the 2022 Paul MacIntyre award given by the Institute of Corrosion to a person having an established international reputation in the field of corrosion engineering who has demonstrably advanced European collaboration and international standards development in the field of corrosion engineering.



Cathodic Protection – Standards Making

Chris Lynch

February 9th 2023

What is a Standard?

A standard is a **normative** document. According to ICorr CP training notes a normative documents is defined as:

“.....a document that provides rules, regulations, guidelines or characteristics for activities or their results.”

But, What is a standard? Again, according to ICorr CP training notes the definition of a standard is:

“Provides rules, guidelines, or characteristics for activities and their results. Aimed at achieving optimum degree of order in a given context. Established by consensus and approved by a recognized body, e.g. BS EN 12954 & BS EN 13509. Standards are issued by “Standards Bodies” authorised in each country to issue such documents.”

BS 0:2021 adds the note:

“Standards are based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits.”

Put More Simply....

The British Standards Institute - **bsi.** advises the following:

Standards

Standards provide the knowledge that organizations need to succeed.



Standards are an agreed way of doing things. They give organizations a set of tools with the potential to help them perform better and compete strongly

Interesting Points About Standards

Users are responsible for their correct application

They are used at the user's own risk

Compliance does not confer immunity from legal obligations

Users accept responsibility and liability not bsi

Standards are not legislation – they are examples of good practice and can be used as evidence of due diligence

The Corrosion Industry in BSI

There are over 50,000 British Standards covering all kinds of services and sectors including, design, installation, operations and maintenance, testing and management. This requires an army of volunteers and professionals to run.

Committees cover many industrial sectors. Corrosion is included in many of these sectors.

The Cathodic Protection Technical Committee is called GEL/603.

What does that mean?

GEL/603 is in the “Manufacturing” Sector

This means we cover the CP requirements for categories including as pipelines and piping, containers and tanks, concrete and concrete products, metallic surfaces, coatings, shipbuilding, waterway and marine structures And natural gas handling equipment

What is GEL/603s remit?

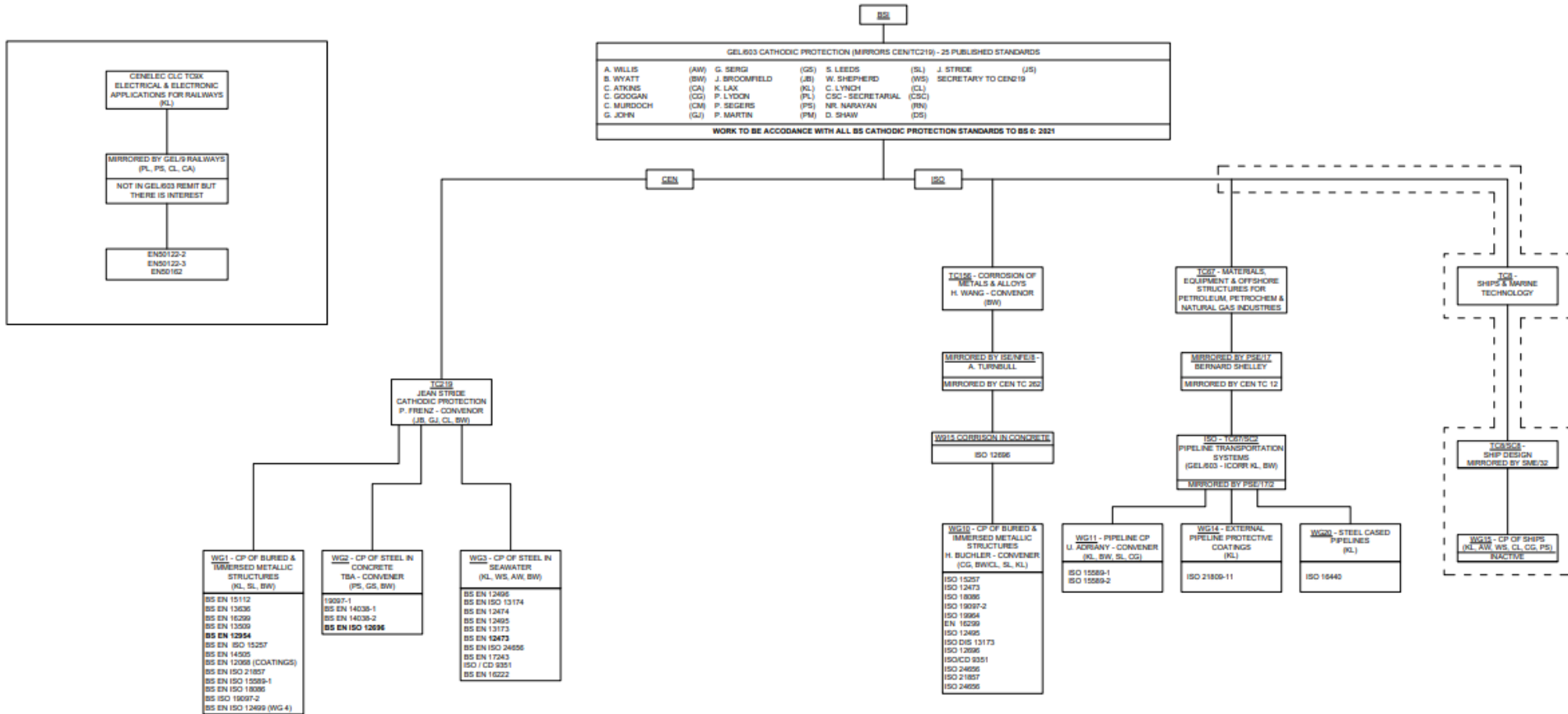
“Under the direction of the Standards Policy and Strategy Committee (SPSC), GEL/603 is responsible for the UK input to CEN/TC219 and standards covering Cathodic Protection in the areas of measurement techniques - Buried and immersed metallic structures - Steel in concrete - Off-shore (sea water) structures - Internal protection and Protection against corrosion by stray current from direct current systems.”

The Structure of GEL/603

The following illustrations simplify the membership, structure and roles of GEL/603

The Structure of GEL/603

GEL/603 CATHODIC PROTECTION RESOURCE TREE



ESTABLISHING A MIRROR GROUP OF AN EXISTING BSI COMMITTEE

ON THE APPROVAL OF THE EXISTING COMMITTEE AND BSI PROGRAMME MANAGER, A MIRROR GROUP CAN BE SET UP ON PROVISION OF A LIST OF MEMBERS/CHAIRMAN AND DETAILS OF WHICH SUB-COMMITTEE OR WORKING GROUP THE NEW MIRROR GROUP WILL SHADOW

ESTABLISHING A NEW BSI COMMITTEE

ON THE APPROVAL OF THE STANDARDS POLICY AND STRATEGY COMMITTEE (SPSC) A NEW BSI COMMITTEE CAN BE ESTABLISHED

The Structure of GEL/603

GEL/603 CATHODIC PROTECTION RESOURCE TREE

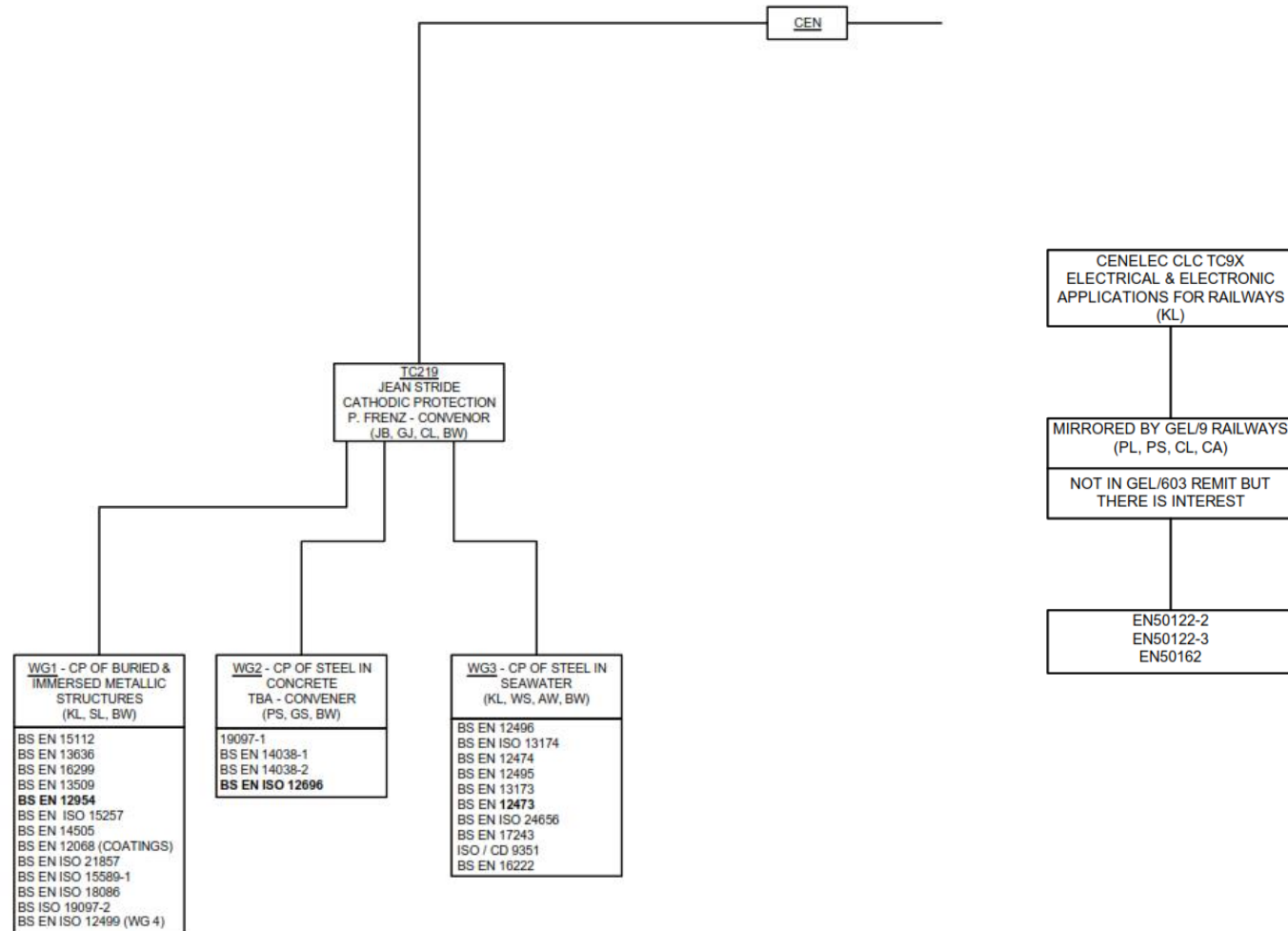
BSI

GEL/603 CATHODIC PROTECTION (MIRRORS CEN/TC219) - 25 PUBLISHED STANDARDS

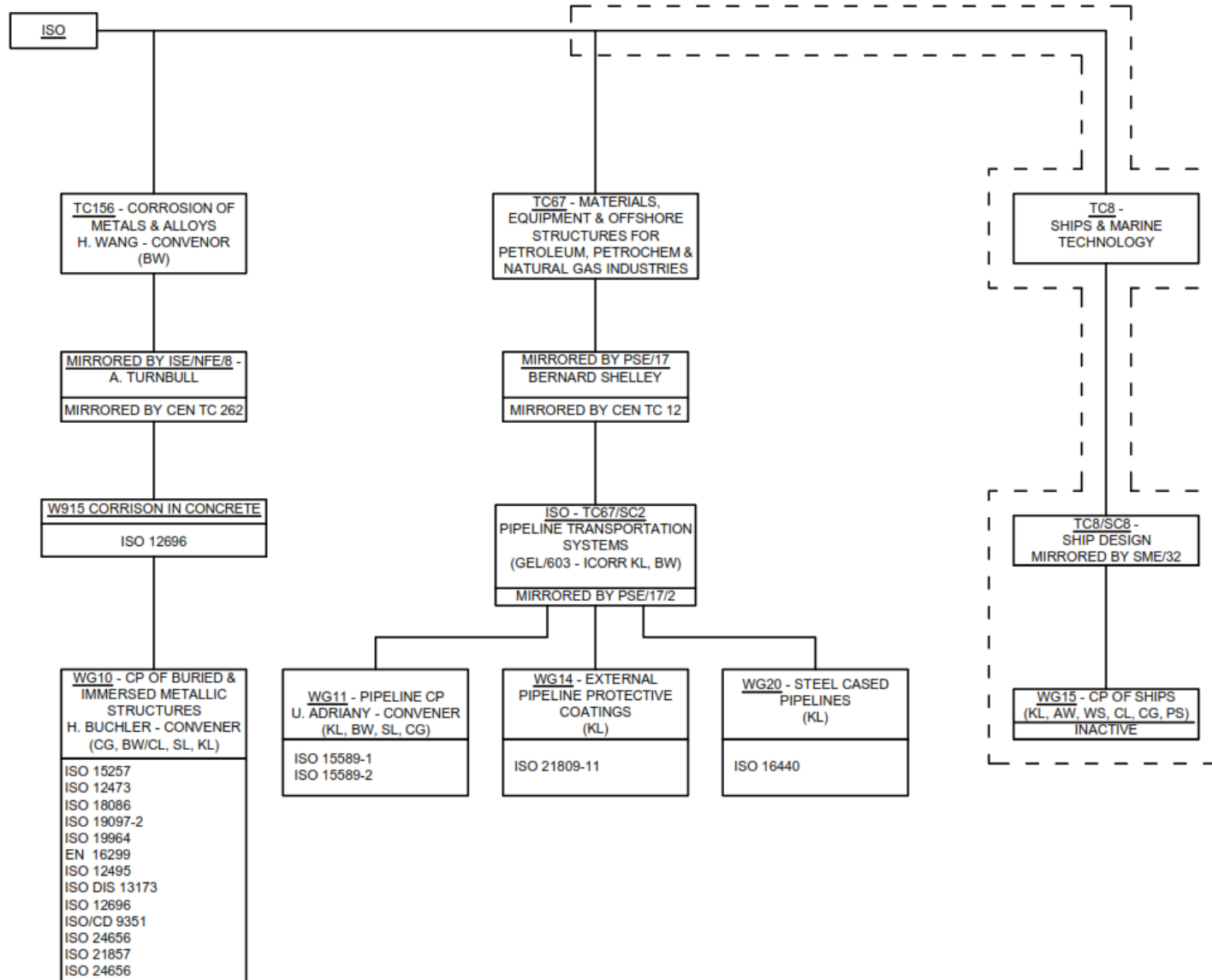
A. WILLIS (AW)	G. SERGI (GS)	S. LEEDS (SL)	J. STRIDE (JS)
B. WYATT (BW)	J. BROOMFIELD (JB)	W. SHEPHERD (WS)	SECRETARY TO CEN219
C. ATKINS (CA)	K. LAX (KL)	C. LYNCH (CL)	
C. GOOGAN (CG)	P. LYDON (PL)	CSC - SECRETARIAL (CSC)	
C. MURDOCH (CM)	P. SEGERS (PS)	NR. NARAYAN (RN)	
G. JOHN (GJ)	P. MARTIN (PM)	D. SHAW (DS)	

WORK TO BE ACCORDANCE WITH ALL BS CATHODIC PROTECTION STANDARDS TO BS 0: 2021

The Structure of GEL/603



The Structure of GEL/603



Published CP Standards

Reference	Title
BS ISO 19097-2:2018	Accelerated life test method of mixed metal oxide anodes for cathodic protection. Application in soils and natural waters
BS ISO 19097-1:2018	Accelerated life test method of mixed metal oxide anodes for cathodic protection. Application in concrete
BS EN ISO 18086:2020	Corrosion of metals and alloys. Determination of AC corrosion. Protection criteria
BS EN ISO 15589-1:2017	Petroleum, petrochemical and natural gas industries. Cathodic protection of pipeline systems. On-land pipelines
BS EN ISO 15257:2017	Cathodic protection. Competence levels of cathodic protection persons Basis for certification scheme
BS EN ISO 13174:2012	Cathodic protection of harbour installations
BS EN ISO 12696:2022	Cathodic protection of steel in concrete
BS EN 17243:2020	Cathodic protection of internal surfaces of metallic tanks, structures, equipment, and piping containing seawater
BS EN 16299:2013	Cathodic protection of external surfaces of above ground storage tankbases in contact with soil or foundations
BS EN 16222:2012	Cathodic protection of ship hulls
BS EN 15112:2022	External cathodic protection of well casings
BS EN 14505:2005	Cathodic protection of complex structures
BS EN 14038-1:2016	Electrochemical realkalization and chloride extraction treatments for reinforced concrete. Realkalization
BS EN 14038-2:2020	Electrochemical realkalization and chloride extraction treatments for reinforced concrete. Chloride extraction
BS EN 13636:2004	Cathodic protection of buried metallic tanks and related piping
BS EN 13509:2003	Cathodic protection measurement techniques
BS EN 13173:2001	Cathodic protection for steel offshore floating structures
BS EN 12954:2019	General principles of cathodic protection of buried or immersed onshore metallic structures
BS EN 12499:2003	Internal cathodic protection of metallic structures
BS EN 12496:2013	Galvanic anodes for cathodic protection in seawater and saline mud
BS EN 12495:2000	Cathodic protection for fixed steel offshore structures
BS EN 12474:2001	Cathodic protection for submarine pipelines
BS EN 12473:2014	General principles of cathodic protection in seawater
BS EN 12068:1999	Cathodic protection. External organic coatings for the corrosion protection of buried or immersed steel pipelines used in conjunction with cathodic protection. Tapes and shrinkable materials

The members of GEL/603

Recognised experts in specific sectors.

Members are supported by a secretarial system called csc and coordinated (some might say harassed) by a Chair

There are currently 17 members of GEL/603 covering the 4 key CP sectors

Members can and frequently do also work in other key standards bodies e.g. CEN and ISO often concurrently

Working in other standards bodies requires one to be either a member of a mirror group or a member of a working group of those bodies

What is expected?

Contribution – It is a role that requires dedication and spending time on a regular and voluntary basis.

Code of Conduct – There is an expectation that members behave and contribute in an ethical, professional and polite manner so as not to put BSI or themselves, or their colleagues in disrepute.

Patience and Respect – You should not be surprised to know that not everyone agrees with you.

What Do We do?

Work can be on existing standards for routine review every 5 years e.g. BS EN 12696 or on new standards e.g. BS EN ISO 24656.

Members meet to discuss current best practice and understanding, state of the art science and latest technologies.

What's the job?

- Currently there are standards in progress e.g. BS EN ISO 15589-1, ISO/CD 9351 and more going through routine review stages
- We are custodians of 26 published standards covering all 4 main sectors
- We have formed mirror groups for CEN and ISO working groups (WGs)
- We vote regularly on proposed standards
- We compile comments on all work proposals or on request
- Some of us are members in ISO and/or CEN WGs
- Some of us can be nominated to work on specific WGs
- Some are conveners of other WGs

But what do I get.....?

Financially – Nothing. You can get some expenses for work, but this is for meeting attendance and is capped.

Professionally – Everything. It is one of the best ways to enhance and enrich your knowledge and is the most rewarding way to do it.

Plus;

- Help improve the quality of life and safety of others
- Expand your professional network
- Gain recognition for making a valued contribution
- Progress your career gaining new skills and ongoing CPD
- Make a difference

But.....it takes **effort** and **commitment**.

Membership

- Applications are via BSI centralised system.
- News committee members not already a member of another BSI committee should seek membership by submitting their application form and CV via the new membership page on the BSI website.
- Usually through nomination by a trade association or organisation which requires a letter/email from their nominating body with the nominees full contact details and a brief description of his/her expertise.
- Alternatively, members may join in one of the following categories:
 - UK Expert – UK expert to an International or European Working Group.
 - Individual - If there are only one or two companies in UK that can provide specific input - [e.g. company name] or [e.g. test method expert].

Membership

- Extract taken from BS 0:2021 Clause 7.2 Committee Constitution:
 - Committee membership is at the sole discretion of BSI. It cannot be claimed as of right
 - It is not granted to any individual, organization or company seeking only to advance its own interests
 - BSI is not obliged to provide reasons for refusing membership
 - It is generally expected that those sitting on a committee will:
 - i) be able to demonstrate technical expertise or relevant knowledge or experience in some areas of the committee's work
- and
- ii) represent a collective body (nominating organization) that has a legitimate interest in the work of the committee.

You get the idea?

It can take some time to understand how the system works.....but that's OK. There is lots of help.





Q and A Session

Paper 3 – Ken Lax





Bio – Ken Lax



Ken Lax is a Chartered Engineer, Fellow of the Institution of Engineering and Technology (FIET), Fellow of the Institute of Corrosion (FICorr), NACE Corrosion Specialist. Member of **fkks** (Society of German CP Experts), CEFRAFOR (French Corrosion Society), CEOCOR (European Corrosion Group). Member of Pipeline Industries Guild and participate in technical panels. Represents UK as technical expert for CP, Electrical Interference, Coating and Surface Preparation for buried structures and above ground storage tanks. Represents UK as technical expert for railway electrical standards (EN 50122-1, 50122-2, 50122-3, 50162). Today's presentation is about EN ISO 21857, which deals with stray current interference to buried or immersed pipelines.

BS EN ISO 21857:2021

Prevention of corrosion on pipeline systems influenced by stray currents

PREPARED BY: Ken Lax CEng, FIET, FICorr, NACE Corrosion Specialist



AUTHOR

Ken Lax – Corroconsult UK Ltd

Telephone: 01952 740234

Mobile: 07768 355670

Email: ken.lax@corroconsult.com

WHAT YOU WILL BE HEARING ABOUT

Definition of cathodic protection

Shortcomings in CP training and certification

Relevance of pipe-to-soil potentials

Sources of interference (obvious and not so obvious)

Measurement techniques

Circuit Analysis (Kirchhoff and transmission lines)

Data analysis Q factor

Harmful effect of CP engineers (not to be underestimated)

Outline of the standard

INTERESTING THINGS

If the nucleus of an atom was the size of a football, the nearest electron would be half a mile away. The rest of the atom is empty space.

If you were to suck out the space from every atom in your body you would be the size of a grain of salt (but still weigh the same).

If you did this for every human on the earth, it would fit inside an apple.

Jim Al-Khalili

This idea of scale is well worth remembering when considering stray currents, cathodic protection and current flow through coatings.

SHORTCOMINGS IN CP TRAINING

The concept of cathodic protection is very simple and easily understood by all. You don't need a degree in physics, electrical engineering, electrochemistry or metallurgy to understand it. (Practical applications can sometimes be a bit tricky).

Those of us who participate in standards development and training are all guilty of presenting a simplified version of cathodic protection to aid understanding.

BS EN 15589-1 provides a very handy table (Table 1) that gives a range of potential values that indicate cathodic protection has been achieved, and values beyond which over-polarisation can cause coating damage and under-polarisation which will allow corrosion to proceed.

CAUTION



When you are dealing with CP you don't need to do too much maths.

Stray current is a different matter altogether.

It will help if you have a good understanding of matrix algebra to solve all the equations that the application of Kirchhoff's Laws develops.

A good understanding of AC theory and the associated maths will help with induced AC, assessing the influence of harmonics and solving Carson's equations.

Solving first order differential equations will help with the analysis of magnetic and electric fields.

The Fourier transform will help with complex AC waveforms. As will an understanding of RMS and peak-to-peak measurements.

Mitigation measures can require changes to the source of the interference, e.g. railway systems, and this will require a multi-disciplinary input.

ISO 15589-1 TABLE 1 (extract)

Table 1 — Free corrosion potentials, protection potentials, and limiting critical potentials of common metallic materials in soils and waters (except seawater) measured against CSE

Metals or alloys	Environmental conditions	Free corrosion potential range (indicative values)	Protection potential (IR-free)	Limiting critical potential (IR-free)
		E_{cor} V	E_p V	E_l V
Carbon steels, low alloyed steels and cast iron	Soils and waters in all conditions except those hereunder described	-0,65 to -0,40	-0,85	a
	Soils and waters at $40\text{ °C} < T < 60\text{ °C}$	—	b	a
	Soils and waters at $T > 60\text{ °C}$ ^c	-0,80 to -0,50	-0,95	a
	Soils and waters in aerobic conditions at $T < 40\text{ °C}$ with $100 < \rho < 1\ 000\ \Omega\cdot\text{m}$	-0,50 to -0,30	-0,75	a
	Soils and waters in aerobic conditions at $T < 40\text{ °C}$ with $\rho > 1\ 000\ \Omega\cdot\text{m}$	-0,40 to -0,20	-0,65	a
	Soils and waters in anaerobic conditions and with corrosion risks caused by Sulfate Reducing Bacteria activity	-0,80 to -0,65	-0,95	a

DEFINITION OF CATHODIC PROTECTION

Given the protection potentials given in Table 1 you could easily assume that cathodic protection can be defined by achieving a certain potential.

BS EN ISO 8044:2020 defines cathodic protection as “electrochemical protection created by decreasing the electrode potential to a level at which the corrosion rate of the metal is significantly reduced”. Notice there are no potential values given.

So as well as being wary of get-rich-quick advertisements on YouTube, be wary of anyone who tells you that the cathodic protection pipe-to-soil potential value defines whether cathodic protection has been achieved.

STRAY CURRENT STANDARDS

BS EN ISO 21857 is the first pipeline standard for stray current. Mainly deals with DC but there is a short section on AC calculations that does not appear in the AC criteria standard (BS EN ISO 18086).

For DC railway systems there are three standards, 50122-1, 50122-2 and 50122-3 that have some relevance. Simply put, -1 deals with safety earthing, -2 deals with construction measures that can reduce stray currents, and -3 tells you how to deal with AC and DC interfaces (more about this later). There is also 50162 (another railway standard) that tells you how to deal with the stray currents that you get if you don't follow -2.

50162 is presently up for review, although there is some opposition from the railway industry to renewing it.

Pipeline standard 50443 deals with electromagnetic interference.

RELEVANCE OF PIPE-TO-SOIL POTENTIALS

Just what is interference?

In the context of stray currents we are either looking at potential gradients or electromagnetic fields.

It is hard to envisage what is going on in the soil with regards to earth currents, induced voltages, earthing systems and so on, and how they effect what you are measuring.

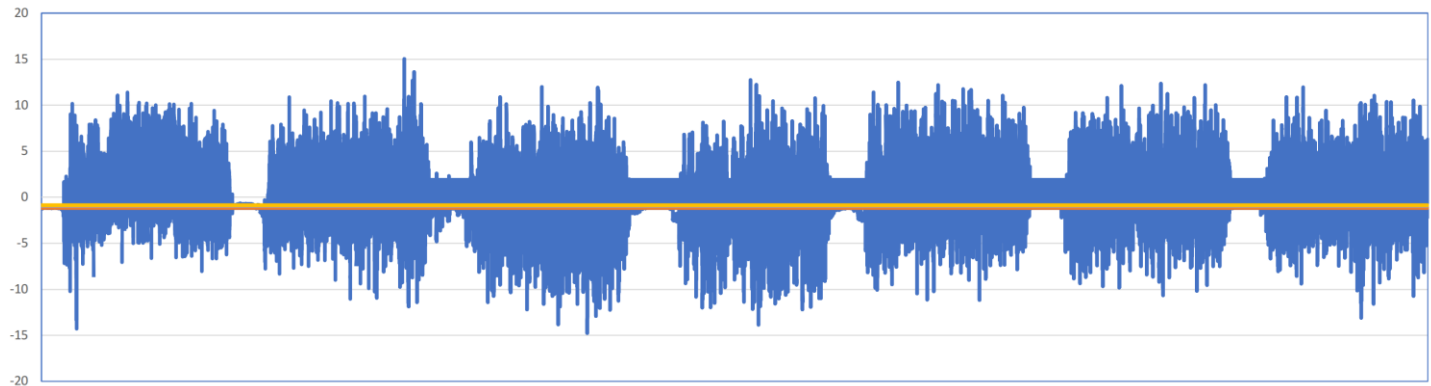
An analogy that sometime helps, is to imagine this:

A super tanker moored to a deepwater jetty in choppy seas. You are in a small boat trying to measure the water depth beneath your boat. Your boat goes up and down with the waves, but the super tanker doesn't move.

This is pretty much what happens when you try to measure a pipe to soil potential in an area affected by stray currents.

RELEVANCE OF PIPE-TO-SOIL POTENTIALS

In interference situations the measured potentials can vary wildly and it can be difficult to make sense of them. Using digital instruments with three decimal places on the measured values does not help either.



SOURCES OF DYNAMIC INTERFERENCE

- 1. Railways (AC and DC)
- 2. High Voltage transmission systems
- 3. Photovoltaic power systems
- 4. Wind power systems.
- 5. Space Weather.
- 6. Tidal fluctuations
- 7. High Voltage AC systems

SOURCES OF INTERFERENCE

When we think of interference, traction systems are usually the first things that come to mind.

Railway, tram and metro systems come in many shapes and forms. Generally speaking DC systems are used for regional systems and AC systems for longer distances. This is mainly related to the efficiency of power transfer in AC and DC. Nevertheless, you can also find long-distance DC systems in some parts of the world.

A simple application of Ohms Law will alert us to the fact that the best way to minimize the generation of stray currents is to have a high resistance between the rails and earth and a low resistance in the electrical return circuit.

SOURCES OF INTERFERENCE DC RAILWAYS

The London Underground is mainly a four rail system. One line for the positive source, one line for the negative source and two running rails. In this configuration the running rails do not need to be insulated from the ground/earth.

The London Overground is mainly a three rail system. One for the positive source, and the two running rails are also used for the negative return circuit.

In this case the running rails have to be insulated from the ground/earth. This is known as a floating earth system because the traction earth, and the safety earth are separate.

Electrical interference to pipelines is caused by currents returning via the soil and adjacent pipelines.

SOURCES OF INTERFERENCE AC RAILWAYS

AC railways are usually driven from a 25 kV overhead power line. Most long-distance and high-speed trains in Europe are configured in this way.

The running rails and the overhead line equipment are all earthed.

Electrical interference is caused by the changing magnetic field that is associated with the current. We will talk about induction a little later on in the presentation.

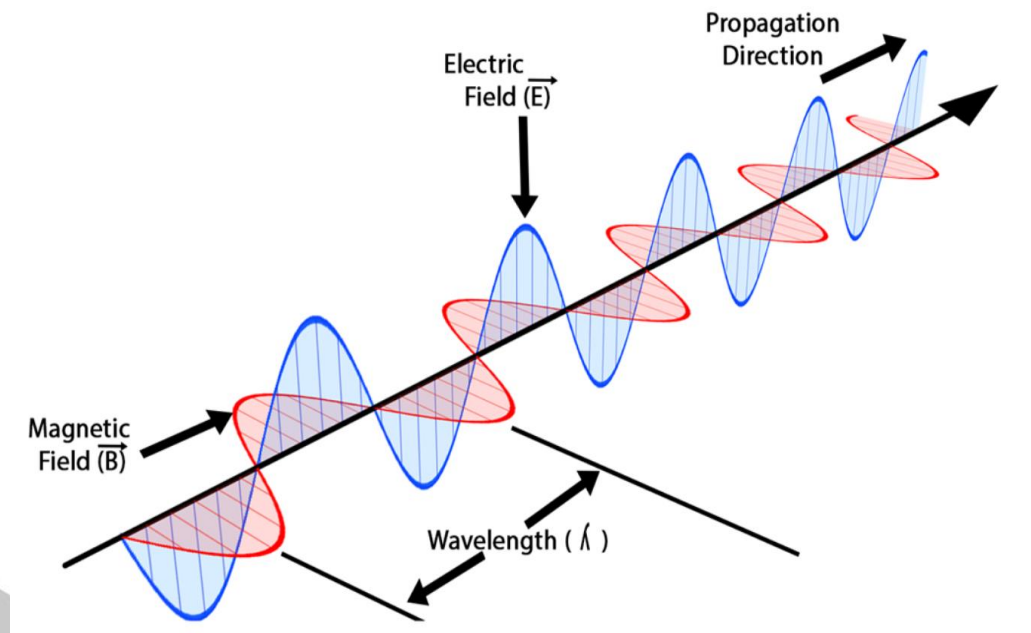
SOURCES OF INTERFERENCE AC RAILWAYS

AC behaves differently to DC. The calculations required to estimate the corrosion risk from induced AC can be quite complicated.

Here are the key points to understanding AC corrosion:

1. Every electrical current has a magnetic field associated with it. The two fields are inseparable.
1. Fluctuating AC (in the UK it fluctuates 50 times a second) will produce a pulsing magnetic and an electric field. The fields are at right angles to each other.

**SOURCES OF INTERFERENCE
AC RAILWAYS
Electromagnetic Wave**



SOURCES OF INTERFERENCE AC RAILWAYS

1. If a conductor is placed in a magnetic field then a voltage will be induced into the conductor. (This is the principle on which electric generators work).
2. The greater the magnetic field, and the faster it changes, the greater the induced voltage.
3. Transmission power lines operate at various voltages, ranging from about 5,000 Volts to 600,000 Volts. (AC railways are generally at 25,000 Volts)
4. The induced voltage can cause corrosion if it forces current to discharge through a coating defect.
5. The induced voltage can also be sufficiently high to give someone an electric shock if they touch an above-ground part of the pipe (e.g. valve).

AC mitigation is an important consideration these days since there are many pipelines that run in so-called energy corridors, which conveniently sits them close to railway systems.

SOURCES OF INTERFERENCE PHOTOVOLTAIC SYSTEMS

This is only a problem with industrial PV systems. PV systems work by converting solar radiation into electrical energy.

The energy is collected from many panels and the DC energy is sent to a central collection system. The DC is then converted to AC by electronic means (it basically chops the DC up into discrete packets of energy and re-constitutes it as a sinusoidal 50 Hz AC form). The widget that performs this conversion is known as an inverter.

A key factor to watch is the isolation resistance between the panels and the earth. This is normally automatically monitored by the operator, but they are happy to operate with significant current leakage to earth.

During the inversion process some pretty horrible shaped waveforms can be generated before they are formed into a perfect sine wave suitable for squirting into the National Grid. Horribly shaped waveforms produce harmonics, and harmonics can change the energy of the wave.

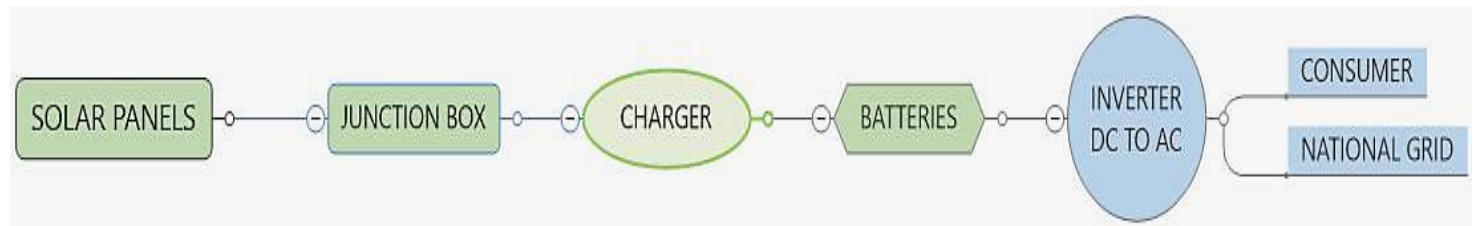
**SOURCES OF INTERFERENCE
PHOTOVOLTAIC SYSTEMS**



**SOURCES OF INTERFERENCE
PHOTOVOLTAIC SYSTEMS**



SOURCES OF INTERFERENCE PHOTOVOLTAIC SYSTEMS



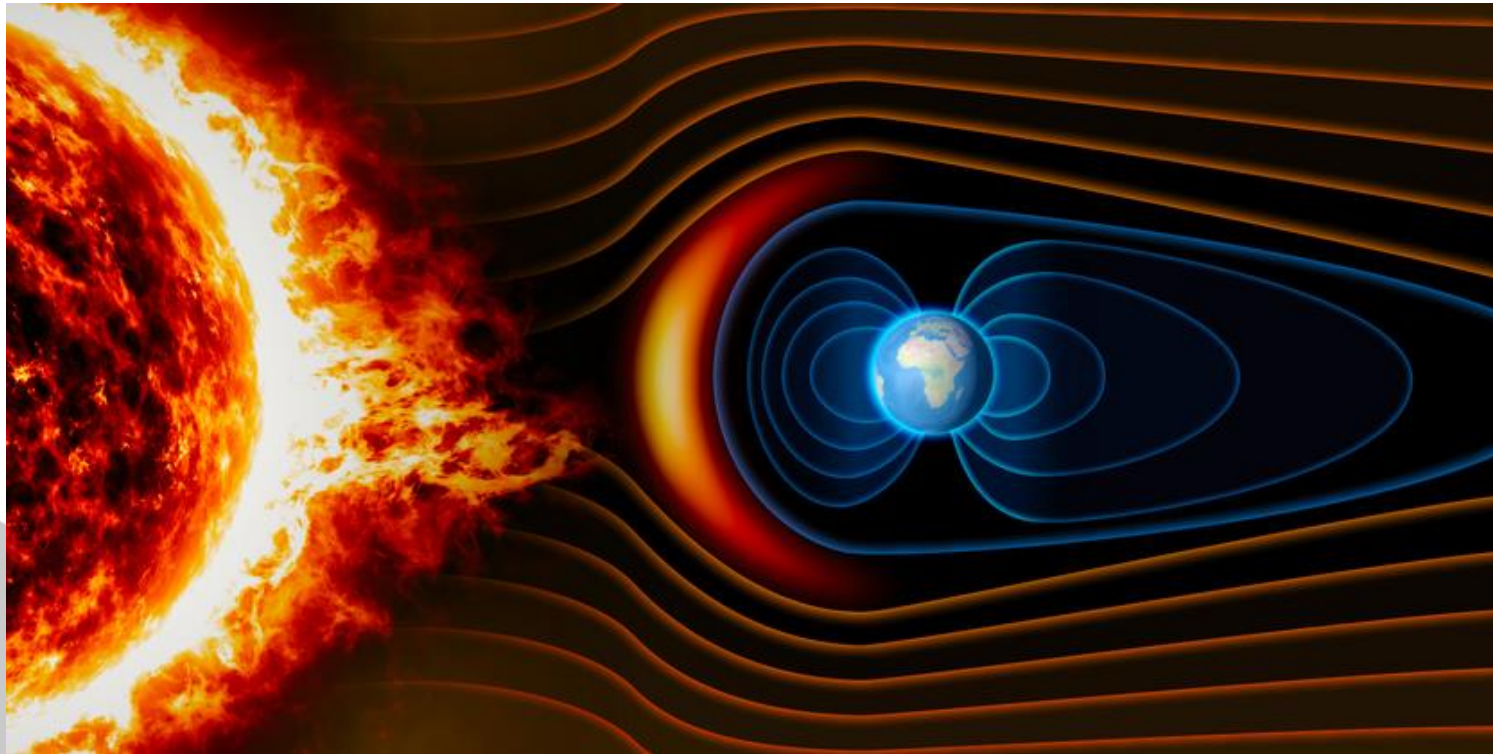
SOURCES OF INTERFERENCE WIND POWER

Electrical interference can originate from wind power systems in very much the same way as for other HVDC or HVAC systems.

It rather depends on how the voltage is transferred to the national grid and how the AC voltage is generated.

SOURCES OF INTERFERENCE SPACE WEATHER

Solar events can have a significant effect on the earth's magnetic field.





WHY SHOULD WE WORRY ABOUT TELLURIC CURRENT EFFECTS?

Largest recorded storm was the Carrington event in 1859. It damaged parts of the U.S. and European telegraph systems, started fires and gave the operators electric shocks.

U.S. Sea mines were detonated in 1972 in South Vietnamese waters by a geomagnetic storm.

In 1989 a geomagnetic storm induced currents in the ground that were so large that they disrupted electricity supply throughout most of Quebec and caused aurora as far south as Texas.

In 2003 the Halloween Storm impacted power grids, airline flights, satellites, GPS etc.

Estimated costs to repair infrastructure if there is another Carrington Event is between 0.6 and 2.6 trillion dollars in the USA alone, and would take more than 5 years to restore the terrestrial systems. Statistically, we are overdue a massive storm.

SOURCES OF INTERFERENCE TIDAL FLUCTUATIONS

Movement of charged particles across a pipeline in water can cause potential variations at the landfall.

This interference is more common in areas of fast moving currents and salty water.

**SOURCES OF INTERFERENCE
HIGH VOLTAGE AC**

Mainly induced voltages but there can also be
conductive effects

BS EN ISO 21857

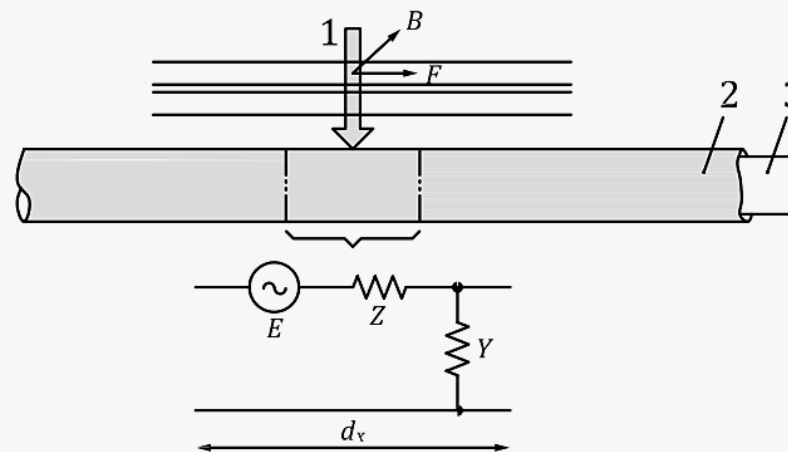
Provides guidance for measurement, monitoring and evaluation of the electrical interference to pipelines.

Modern standards are what are known as performance standards. This means that they tell you what to achieve but don't necessarily tell you how to achieve it.

In 21857, however, because so much of it is new we have given detailed information and calculation examples in the body of the standard and in informative annexes.

**BS EN ISO 21857
CALCULATIONS**

Annex D. Geomagnetic interference



Key

- 1 incident field
- 2 coating
- 3 pipe steel

- B magnetic field
- F electric field
- d_x distance

Figure D.1 — Schematic of electromagnetic induction in a pipeline and the equivalent circuit for a short pipeline section

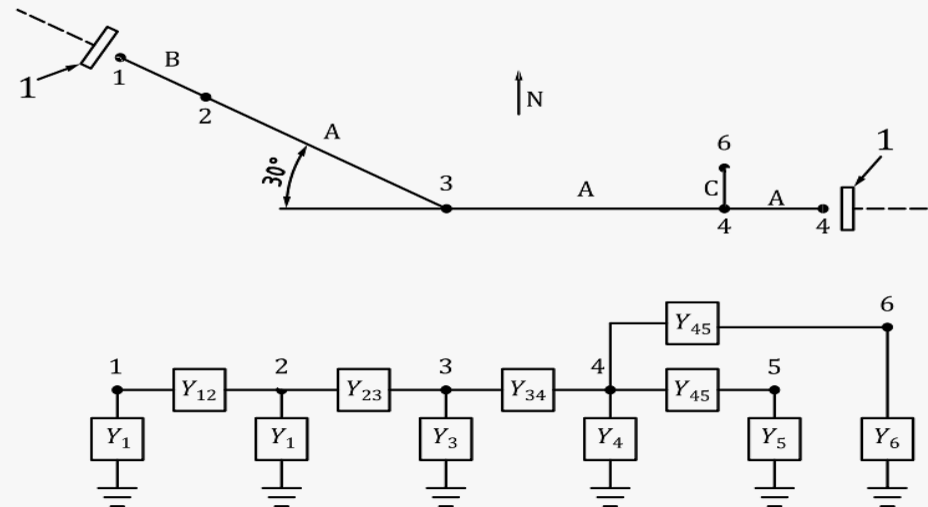
BS EN ISO 21857 CALCULATIONS

Annex D. Geomagnetic interference

D.3 Example model calculation

D.3.1 General

To illustrate how the network modelling can be applied in practice, calculations are presented for the example pipeline network shown in [Figure D.5](#) where sections labelled A, B and C are pipelines with different characteristics. This pipeline contains features that would occur on a real pipeline such as a change in pipeline dimensions, a bend, a junction with a branch line and insulating flanges all of which influence the telluric potentials that are produced.



Key

1 insulating flange

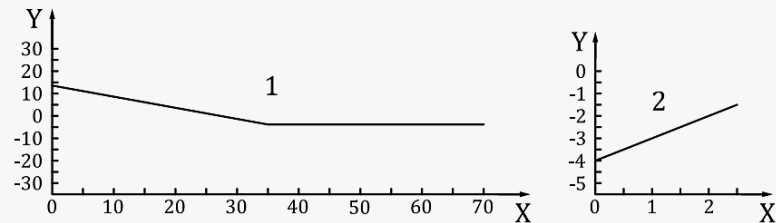
Figure D.5 — Example pipeline and its nodal admittance network model

**BS EN ISO 21857
CALCULATIONS**

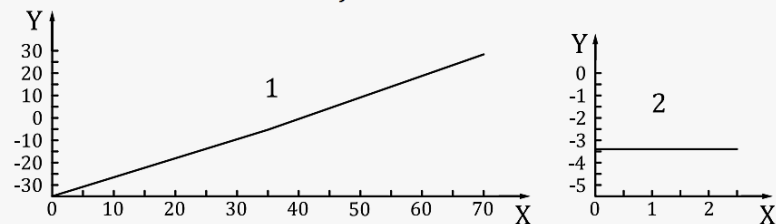
Annex D. Geomagnetic interference

D.3.10 Step 9 Use the nodal voltages to calculate the pipeline potentials within each section

For each section use [Formula \(D.5\)](#) with the end voltages from the tables above to calculate the telluric potential as a function of distance within each section. This gives the results shown in the [Figures D.6 a\) and b\)](#).



a) Northward



b) Eastward

Key

- 1 main pipeline
- 2 branch
- X distance along pipeline, in km
- Y pipe to soil potential, in V

Figure D.6 — Telluric potentials produced by an electric field of $1 \text{ V}\cdot\text{km}^{-1}$

BS EN ISO 21857 CALCULATIONS

Annex F. Alternating current interference

Vector phase current B (A)	$I_b := 500 \angle -120^\circ$
Vector phase current C (A)	$I_c := 500 \angle 120^\circ$
Calculation of mutual impedances (Carson)	
Frequency (Hz)	$f := 50$
Resistivity ($\Omega \cdot m$)	$\rho := 100$
Height of conductor from centre of pipe (m)	$h := 12$
Distance between phase A and B (m)	$d_1 := 8$
Distance between phase B and C (m)	$d_2 := 8$
Distance from centre of pipe to phase B (m)	$d_3 := 15$
	$D_{ap} := \sqrt{(d_2 + d_3)^2 + h^2} = 25,942 \angle 0^\circ \text{ (m)}$
	$D_{bp} := \sqrt{d_3^2 + h^2} = 19,209 \angle 0^\circ \text{ (m)}$
	$D_{cp} := \sqrt{(d_3 - d_2)^2 + h^2} = 13,892 \angle 0^\circ \text{ (m)}$
Equivalent distance from pipeline conductor	
	$D_{ep} := 658,37 \cdot \sqrt{\frac{\rho}{f}} = 931,076 \angle 0^\circ \text{ (m)}$
Geometric mean separation distance	
	$D_{1p} := (\sqrt[3]{D_{ap} \cdot D_{bp} \cdot D_{cp}}) = 19,059 \angle 0^\circ \text{ (m)}$
Mutual impedances	
	$Z_{ap} := 9,869 \times 10^{-4} \cdot f + 1i \cdot 2,8935 \times 10^{-3} \cdot f \cdot \log\left(\frac{D_{ep}}{D_{ap}}\right) = 0,2303 \angle 77,6284^\circ \text{ (\Omega/km)}$
	$Z_{bp} := 9,869 \times 10^{-4} \cdot f + 1i \cdot 2,8935 \times 10^{-3} \cdot f \cdot \log\left(\frac{D_{ep}}{D_{bp}}\right) = 0,2488 \angle 78,56^\circ \text{ (\Omega/km)}$
	$Z_{cp} := 9,869 \times 10^{-4} \cdot f + 1i \cdot 2,8935 \times 10^{-3} \cdot f \cdot \log\left(\frac{D_{ep}}{D_{cp}}\right) = 0,2688 \angle 79,4209^\circ \text{ (\Omega/km)}$
Induced voltage	
	$V_p := I_a \cdot Z_{ap} + I_b \cdot Z_{bp} + I_c \cdot Z_{cp} = 17 \angle -121^\circ \text{ (V} \cdot \text{km}^{-1}\text{)}$

BS EN ISO 21857 CALCULATIONS

Annex I. Q Factor

Assessment of the corrosion risk for steel in concrete or for cathodically protected structures under time variant interference conditions



The following data are required from the most critical location of interference and over a period that covers the most critical interference conditions, e.g. highest anodic interference.

- a) In case of steel in concrete structures:
 - Long term recording results of the potential, E
- b) In case of cathodically protected structures
 - Long term recording results of the on potential, E_{on} , or
- c) In case of coupons
 - long-term recording result of the magnitude and direction of the coupon current (I_{cpn}) from which the coupon current density (J_{cpn}) can be calculated.

A reference potential, E_{ref} (for Method 1) or a reference current density J_{ref} (for Method 2 in case of coupon measurements) that determines whether the present interference is cathodic or anodic, needs to be defined by the operator.

Whenever the potential and current density value is more anodic than J_{ref} and/or E_{ref} then this period of interference is considered to be anodic. Based on the longest anodic period $T_{a,max}$ is determined.

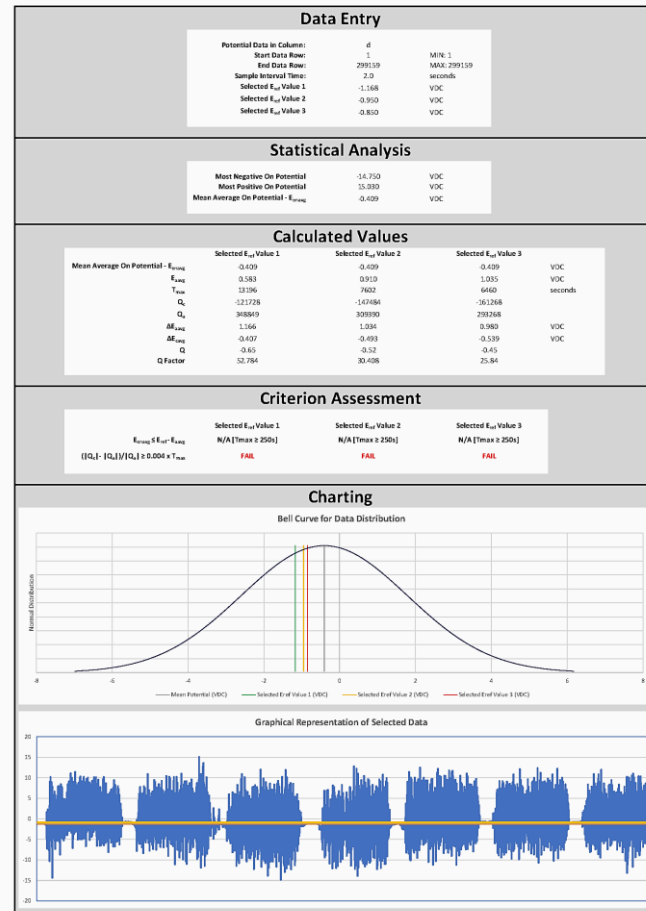
In the absence of interference E_{ref} is the on-potential, E_{on} , of the structure required for effective cathodic protection.

In the case of coupons J_{ref} is defined as the current density that is required to achieve the protection potential. The commonly used values in [Table J.1](#) should be considered.

Table J.1 — Examples of reference levels

	Examples of reference levels	Comments
Cathodically protected structures buried in soil (i.e. particle size smaller than medium gravel as defined in ISO 14688-1) or immersed in water with increased hardness (total hardness exceeding 1,3 mmol/l)	$E_{ref} = -1,0 V_{CSE}$ $J_{ref} = 0,02 A \cdot m^{-2}$	The assessment becomes more conservative with the E_{ref} value being defined more negative or with the J_{ref} value being defined higher (more cathodic)
Cathodically protected structures buried under exceptional bedding conditions, i.e. soft flowing groundwater (total hardness below 1,3 mmol/l) in combination with coarse bedding material (e.g. medium gravel), as defined in ISO 14688-1).	E_{ref} is the on-potential, E_{on} , of the structure required for effective cathodic protection; In the case of coupons J_{ref} is defined as the current density that is required to achieve the protection potential	E_{ref} can be evaluated from operational data, or from theoretical considerations, e.g. taking into account conservative assumptions for the protection potential E_{R-free} , the protection current density (a minimum of 0,2A/m ² should be considered), the geometry of a coating defect and the soil resistivity.

BS EN ISO 21857 Q FACTOR CALCULATIONS



BS EN ISO 21857

Table 1 — Overview of criteria for the assessment of stray current interference

	Non-cathodically protected	Cathodically protected
Steel and cast-iron structures		
Anodic interference (i.e. when the potential is more anodic than the potential during the periods of non-interference) Time constant	Anodic potential shift (relative to E_{cor}) ΔE_a (IR-drop included): $\Delta E_a \leq 300$ mV ($\rho > 200$ Ω -m) or $\Delta E_a \leq 1,5$ mV(Ω -m) ⁻¹ • ρ (15 Ω -m $\leq \rho \leq 200$ Ω -m) or $\Delta E_a \leq 20$ mV ($\rho < 15$ Ω -m) or anodic potential shift (relative to E_{cor}) $\Delta E_{a,IR-free}$ (IR- drop excluded): $\Delta E_{a,IR-free} \leq 20$ mV See 8.3.1.1.2	IR-free potential $E_{IR-free}$: $E_{IR-free} \leq E_p$ (E_p =protection potential according to Reference [Z]) See 8.3.1.1.3
Cathodic interference Time constant	Cathodic potential shift ΔE_c : $\Delta E_c \leq 500$ mV (IR-drop included) See 8.3.1.2	
Anodic/cathodic interference Time variant	Average anodic potential shift (relative to E_{cor}) $\Delta E_{a,avg}$; $\Delta E_{a,avg} \leq \Delta E_a$ See 8.3.1.1.2	IR-free potential $E_{IR-free}$: $E_{IR-free} \leq E_p$ (E_p =protection potential according to Reference [Z]) Shift of $E_{on,avg}$: $E_{on,avg} \leq E_{ref} - \Delta E_{a,avg}$ See 8.3.1.1.3 ^a
	Average cathodic potential shift $\Delta E_{c,avg}$: $\Delta E_{c,avg} \leq 500$ mV (IR-drop included) See 8.3.1.2	
All conditions	Corrosion rate design value See 8.2	$v_{cor} \leq 0,01$ mm•a ⁻¹ See 8.2
Steel in concrete without cathodic protection		
Anodic interference Time constant Time variant	Anodic potential shift (relative to E_{cor}) ΔE_a : $\Delta E_a \leq 200$ mV see 8.4.1 $\Delta E_{a,avg} \leq 200$ mV see 8.4.2	
^a Further information can be found in Annexes A and J .		

ISO 21857

The standard is written for pipelines but can also apply to :

- Metal sheathed cables
- Tanks and vessels
- Earthing systems
- Steel reinforcement in concrete
- Sheet steel piling

It gives guidelines for:

- CP designs that might produce stray currents
- Design of pipeline systems
- Selection of appropriate mitigation systems

CONCLUSIONS

The standard is written for pipelines but can also apply to :

- Metal sheathed cables
- Tanks and vessels
- Earthing systems
- Steel reinforcement in concrete
- Sheet steel piling

It gives guidelines for:

- CP designs that might produce stray currents
- Design of pipeline systems
- Selection of appropriate mitigation systems

The standard contains worked examples for calculations and provides more technical information than is usual for a performance standard.



THANK YOU FOR YOUR ATTENTION

We hope that this brief introduction to stray current issues has raised your awareness of the possible sources of electrical interference.

Following the guidelines given in the standard will help you understand the measurement and analysis that are required to assess and mitigate the corrosion risks.

Paper 4 – **George Winning**





Bio – George Winning



George Winning has been working in the oil and gas industry for 35 years in several roles but specialises in production chemistry and corrosion. He has been a member of the Institute of Corrosion for over 30 years and is a fellow of the institute. During his time as a member, he has been involved in the branch committees in both Aberdeen and London. He is currently Vice Chair of the London Branch and sits on council.



Production Chemistry for Corrosion Engineers - PC4CE

An Introduction

Based on a course donated to the Institute
of Corrosion by BP

What is Production Chemistry?

3 key areas in Production chemistry

Separation

Key to selling the product (oil, condensate and gas)

Affects quality and value of the product

Flow assurance

Assurance of production

Maximisation of value of the assets

Integrity

Longer term issues

Not as visible as the other two, particularly in early years of production

Can have catastrophic effects in the long term- Cracking issues

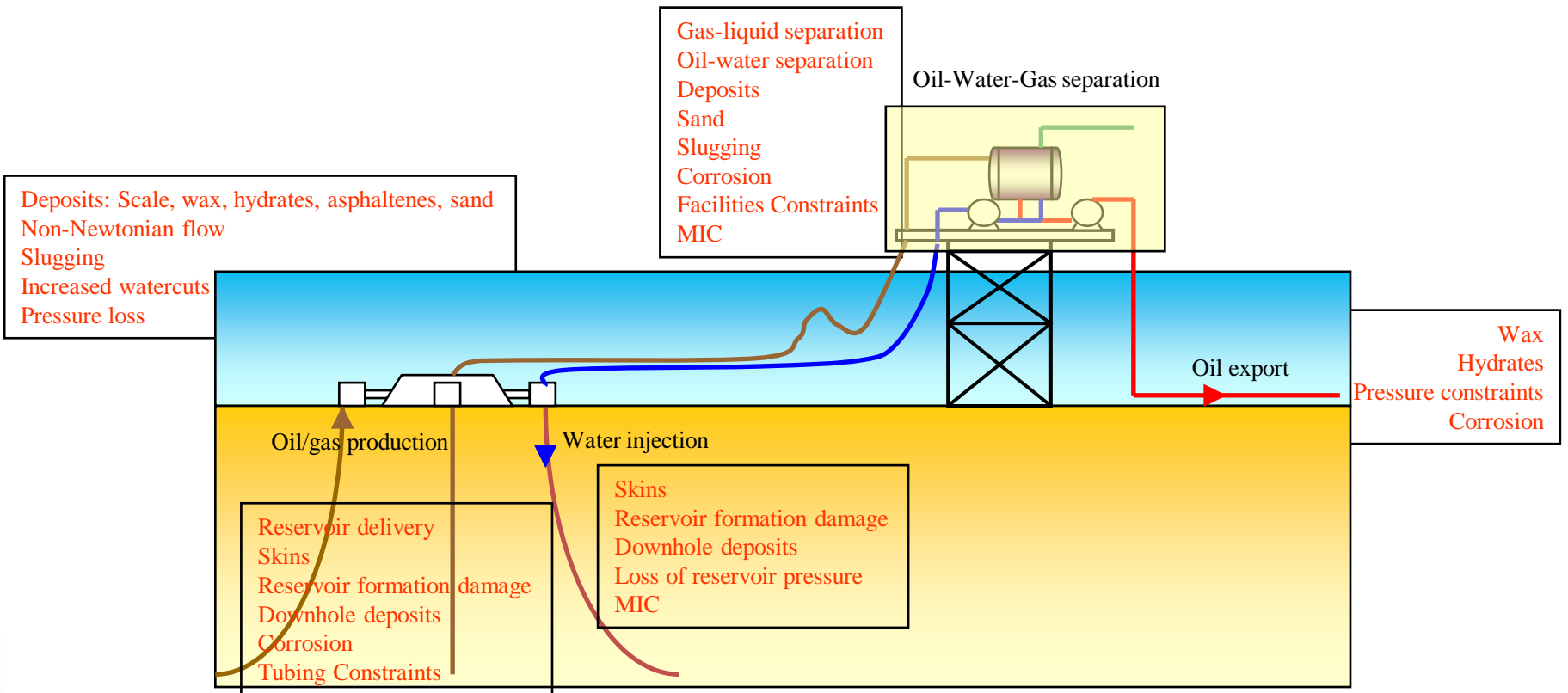
The common point it is all are based on the fluids characteristics or properties

The Chemistry of the Produced Fluids - Production Chemistry

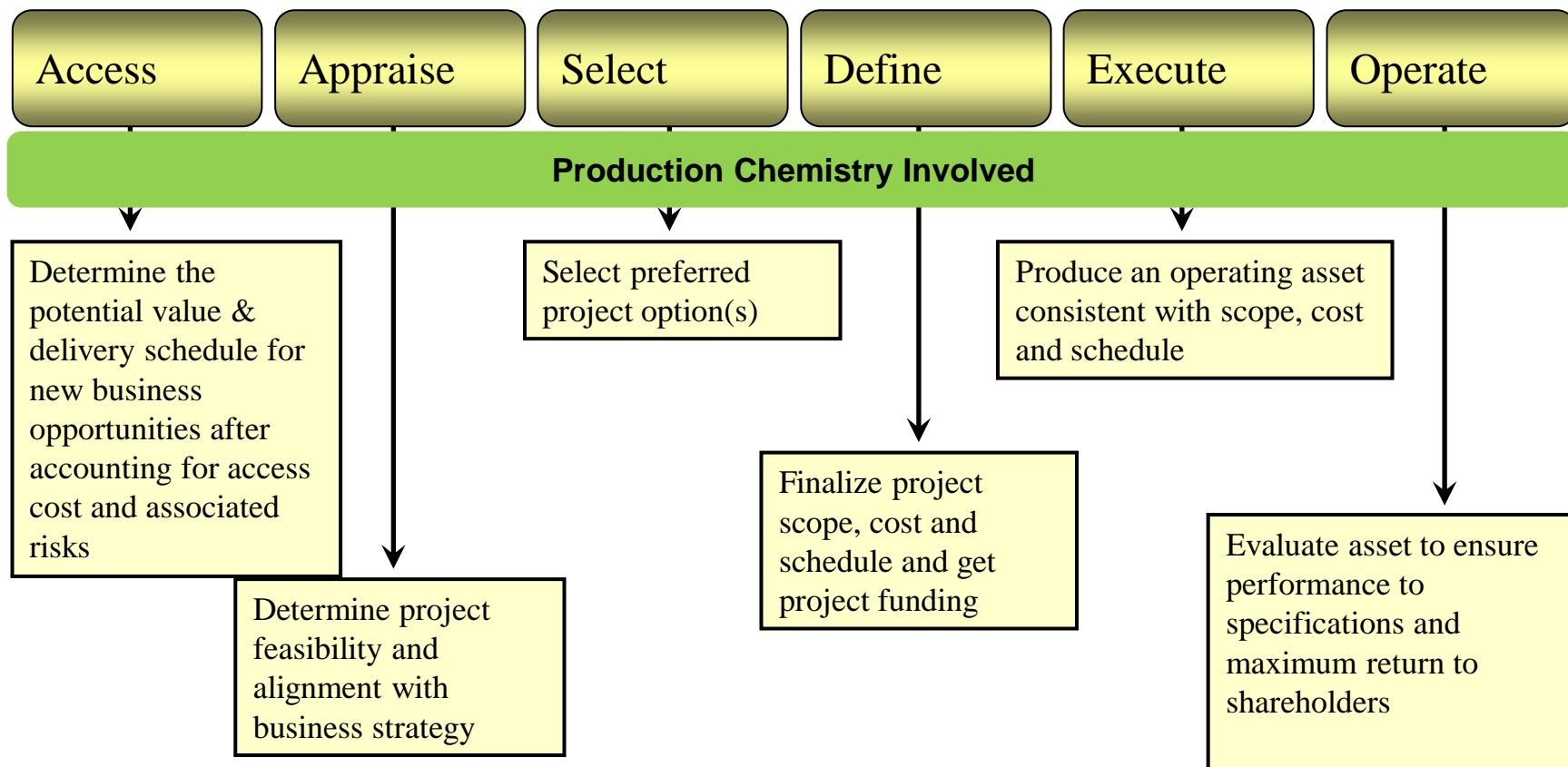
Producing Reservoir Fluids to Surface

- Reduction in pressure
- Reduction in temperature
- Mixing with other produced fluids
 - Gas break out
 - Change in compositions of liquid and gas phases
 - Changes in solubility of dissolved species
 - Wax
 - Hydrates
 - Asphaltenes
 - Scale
 - Changes in volumes of gas and liquid phases
 - Multiphase flow effects
- **UNDERSTANDING THESE EFFECTS IS KEY TO PRODUCTION CHEMISTRY**

Production chemistry options



Where is production chemistry Involved



Production Chemicals - Types

- Scale inhibitors: delay scale nucleation and growth, thereby reducing deposition
- Demulsifiers: coalesce water droplets to facilitate water separation
- Corrosion inhibitors: inhibit corrosion reactions and thus reduce surface metal loss
- Biocides: kill bacteria or stop their growth
- Oxygen scavengers: react with and thereby remove free oxygen
- Antifoam agents: rupture bubble walls, reducing foaming during liquid/gas separation
- Foaming agents: promote foam formation to lift liquid out of wells
- Flocculants: bring solid particles together, facilitating their removal
- Hydrate inhibitors: reduce the thermodynamic or kinetic driving force to hydrates
- Sulphide scavengers: react with and thereby remove sulphide gases
- Wax crystal modifiers: alter wax crystal structure to reduce deposit build up
- Drag reducers: lower energy loss at pipe wall increasing throughput at a given pump pressure
- Naphthenate inhibitors: to delay formation and growth and thus reduce deposition
- Asphaltene inhibitors: to delay or disperse flocculated asphaltenes and thus reduce deposition
- Others: Glycols for dehydration; Water Clarifiers, Deoilers, Coagulants, Amine for CO₂ removal, Scale solvers, wax and asphaltene solvents.

Introduction to Separation



Separation

- Produced fluids from oil and gas reservoirs contain many phases
 - Oil and gas
 - Oil water and gas
 - Gas and condensate
 - Gas and water
 - Are few of the combinations
- To maximise profitability of a field it is key to separate these phases
 - Gas, condensate and oil can be sold
 - Water needs to be disposed of
 - Possibly used for reinjection and pressure maintenance

How is separation achieved

- Hardware
 - Knock out drums
 - Separators
 - Desalters (Electrostatic)
 - Tanks
 - Hydrocyclones
 - Gas flotation devices
 -
- Chemical
 - Demulsifiers / EBs / Viscosity Reducers
 - Deoilers
 - Flocculants
 - Coagulants
 - Antifoams
- Normally a mix of the two

Principals of separation

Stoke's Law determines rate of rise or fall of droplets in a continuous phase.

$$v = \frac{2gr^2(\Delta\rho)}{9\eta}$$

where, v = velocity of rise (or fall)
 g = gravitational constant
 r = droplet radius (note square relationship!)
 $\Delta\rho$ = density difference
 η = viscosity of continuous phase

Stoke's Law is much abused

- Relevant only to isolated, non-deformable spheres
- Brownian motion dominates for small (<1 μm radius and influences motion for drops <50 μm)

Introduction to Flow Assurance



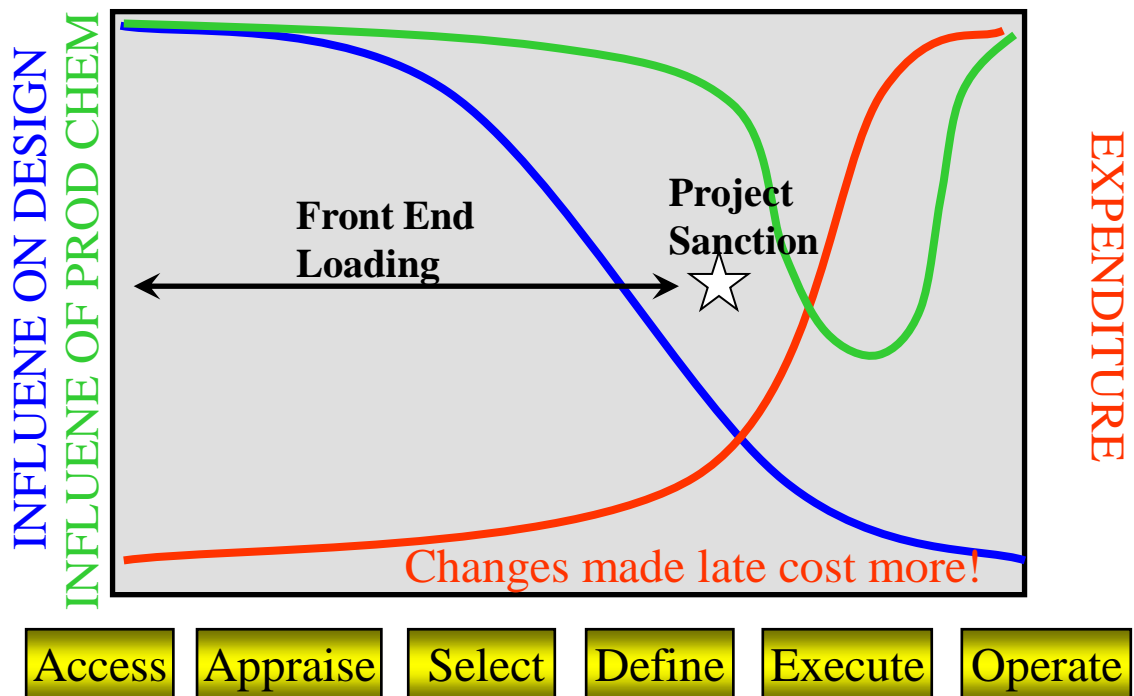
Flow Assurance

- Profit can only be made if you can get the fluids from the reservoir to the customer.
 - Flow assurance is identifying restrictions to flow
 - How this can affect flow
 - How can mitigation can be carried out to ensure flow
 - Physical blocks
 - » Hydrostatic effects
 - » Flow
 - » Pressure
 - » Temperature
 - » Topography
 - Chemical Blocks
 - » Fluid properties
 - » Scale
 - » Wax
 - » Hydrates
 - » Ashphaltenes
 - » Naphthenates
 - » A mix of many of these

Natural Chokes

- There are natural chokes that are dictated by:
 - Reservoir inflow
 - Function of permeability, porosity, fluid properties (density/viscosity)
 - Well Completion
 - Function of tubing size, fluid properties, pipewall surface roughness, well chokes
 - Flowline
 - Function of separator pressure, flowline size, fluid properties, water depth (riser length)
- The available pressure will determine the max rate
- The well, flowline and facilities design will determine the chokes and hence the production rate
- Chokes are areas where the chemistry physical conditions can change
 - Production Chemical requirement can be affected

Project Life Cycle & Production Chemistry Influence



Why Do We Need Production Chemistry

- **Optimise development design (wells to export)**
 - Improve HSE
 - Avoid facility failure
 - Avoid blockages
 - Avoid stuck valves
 - Minimise production problems
 - Avoid blockages
- **Optimise separator performance**
 - Reduce production costs
 - Minimise well interventions
- **Optimise chemical usage**
 - Meet export specifications
- Optimise plant performance
- Maintain license to operate
 - Local regulations for chemicals
 - MOC
 - Disposal specs

Introduction to Integrity Management



Integrity

- Integrity covers
 - Corrosion
 - Materials
 - Corrosion inhibition
 - Oxygen scavenging
 - Microbially Influenced Corrosion
 - Biocides
 - Gas scavenging
 - H₂S scavenging

Definition of Corrosion

- Scientific
 - Electrochemical degradation of metal as a result of a reaction with its environment
- Practical
 - Tendency of metal to revert to its native state
- Economic
 - The total cost of corrosion in the U.S. oil and gas production industry is estimated to be \$1.372 billion annually
 - \$589 million for surface piping and facility costs,
 - \$463 million in downhole tubing expenses, and
 - \$320 million in capital expenditures related to corrosion.

(NACE & CC Technologies 2001)

Factors that Affect Corrosion

- Metallurgy
- Water chemistry
- pH
- Moisture Content
- Temperature
- Agitation (Flow velocity)
- Solids
- Pressure
- Dissolved gases
- Microbial activity
- Presence of organic acids

Corrosion Mitigation

- **Materials Selection**
 - Pick the right material for the environment
 - Determine Life-cycle cost
- **Modify/Isolate the Electrolyte**
 - Chemical Inhibition
 - Coatings
- **Cathodic Protection**
 - External corrosion control for buried/submerged structures
 - Internal corrosion control for process vessels and tanks

Why are we doing this?

Gap in the market

Others are available but not certified

Oil and service companies losing experience.

Status

- Agreement to develop the course
 - Bill Hedges and myself engaged
- Just started preparation of slides
- Schedule
 - Complete end of 2023
- First courses 2024
- Courses will have certification

Questions



Paper 5 – Chris Googan





Bio – Chris Googan



Chris Googan started messing about with Corrosion in 1973. He is now considering taking it up as a full-time profession! More seriously – Chris is a Corrosion Specialist with more than 30 years experience acquired in over 40 countries and is a Materials & Corrosion Engineer at Anticorrosion Engineering Limited. His Experience has been predominantly in the hydrocarbon production industry, but projects also carried out in: refining, chemicals & petrochemicals, shipping, automotive, defence, power generation, water, civil engineering, legal and insurance sectors. Published and presented many papers on: corrosion failures, cathodic protection, coatings, and corrosion management.

Why Do Protective Coatings Fail?

- **Concept**
- **Design**
- **System Selection**
- **Product Quality**
- **Specification**
- **Workmanship**
- **Inspection**



Why Do Protective Coatings Fail?

Chris Googan

Apologies – Chris unable to publish his talk at this time but may be contacted on: chris.googan@anticorr.com should you have any specific Questions.
Thank you for attending.

Paper 6 – Simon Daly



Bio – Simon Daly



Simon Daly is currently a consultant for Safinah group in Gateshead. His role involves providing consulting services to clients ranging from specification writing assistance, through failure investigations and root cause analysis to providing expert opinions to their energy & infrastructure clients. In addition to this role, he has worked for several multinational paint companies in both technical and commercial roles. He started his career formulating protective coatings based around a variety of chemistry types, most notably vinyl esters and epoxy-based materials for elevated temperature service. He is the chair for ISO TC67/WG11/TG3 responsible for several standards relating to coatings used in pressure vessels. Simon has a B. Eng (Hons) degree from the University of Leeds and qualifications in marketing and international sales management. He is an AMPP-certified Senior Corrosion technologist and a professional member of ICorr with over 30 years' experience in the protective coatings field.



Challenges for selecting coatings for the fixed and floating offshore wind industry

Simon Daly
Consultant – Energy & Infrastructure

Setting the economic scene

There is a strong business case for improving anti-corrosion solutions (ACS) for UK offshore wind

“Considering the results to anti-corrosion solution vendors, the three scenarios result in a range of value chain availabilities between £17.3bn and £43.5bn in the wider EU, by 2030; with these numbers more than doubling to £33.6bn and £83.3bn by 2050. “

CAPEX reduction

Year	UK GW	Developer saving £ bn	Vendor value £ bn
2020	8.4	2.7	3.3
2030	25.5	9.2	11.2
2050	60.0	12.8	14.4

Business as usual

Year	UK GW	Developer saving £ bn	Vendor value £ bn
2020	8.4	0.3	1.3
2030	25.5	1.0	4.3
2050	60.0	1.9	5.6

Deployment of novel ACS

Year	UK GW	Developer saving £ bn	Vendor value £ bn
2020	8.4	-0.05	1.7
2030	25.5	-0.04	5.9
2050	60.0	0.5	7.6

Agenda

- ✓ Types of structures
- ✓ Corrosion categories
- ✓ Corrosion protection
- ✓ Coating specifications
- ✓ Secondary factors
- ✓ Summary / improvements



Types of structures

Balance of plant (BOP) is the primary focus of this presentation

- Fixed
 - monopile
 - transition piece
- Floating
- Secondary steel
- OEM items





Types of offshore structures

Coating of internal compartments adds complexity, cost and reduces coating productivity on fixed and floating foundations



Floating foundations

Floating wind adds additional coating requirements to foundation structures

Additional painted secondary steel area

Internal compartments

Significant immersed area /
Fouling control requirements



OSP

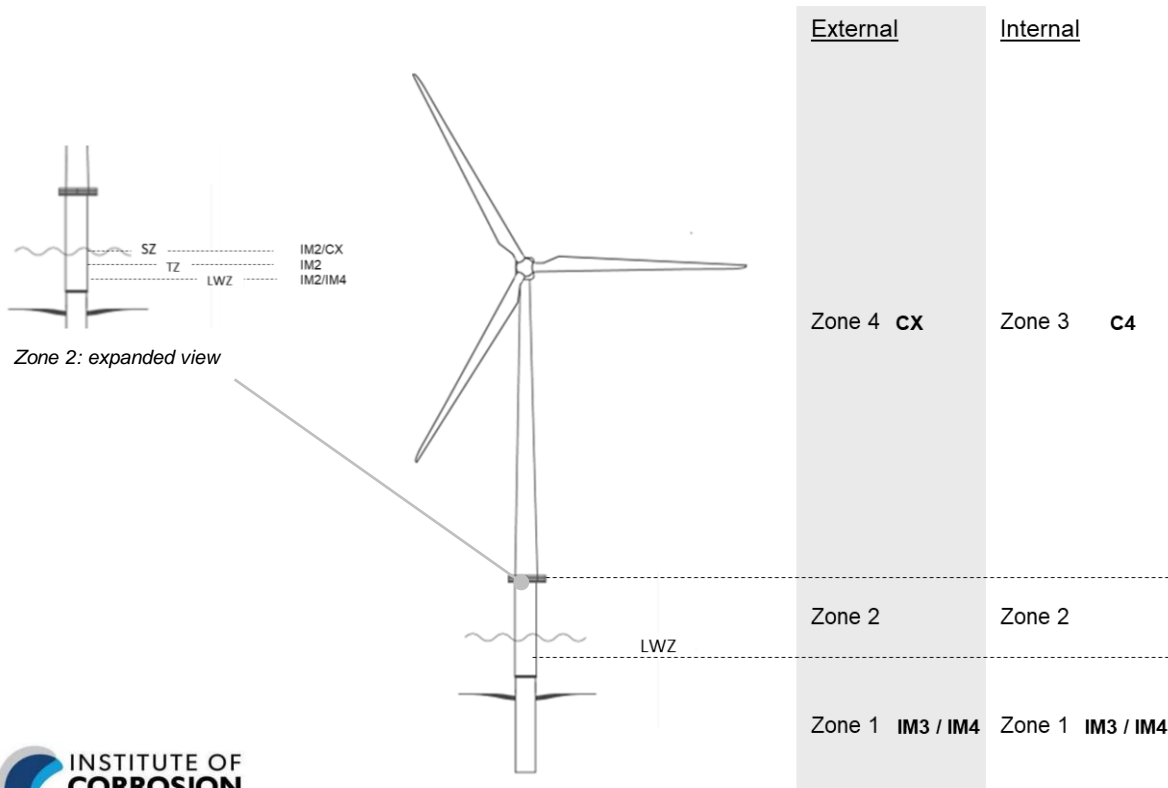
Offshore substation platform (OSP's) look more like traditional oil and gas plant requirements

- Increased atmospheric area
- Deck areas walkways & escape routes
- Increased internal spaces (HVAC controlled)
- Passive fire protection



Corrosion categories

Using VGB / BAM S-21 as an example.



Environment categories as per ISO 12944-2

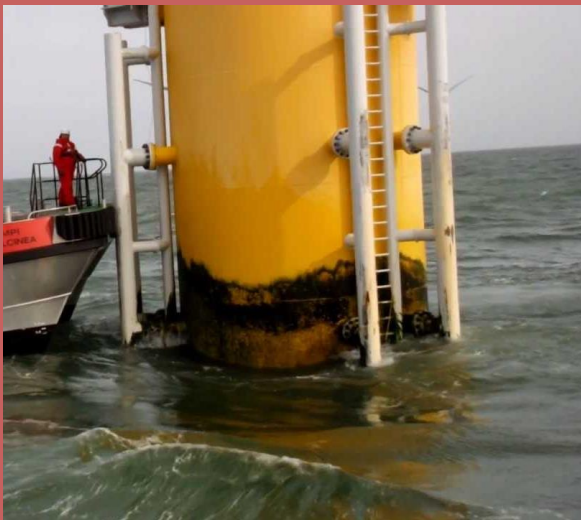
Category	Description	Low Carbon steel corrosion loss p.a. (μ)
C4	High	> 50 - 80
CX	Extreme	> 200 - 700
IM2	Sea or brackish water	Not recommended to try and standardize
IM3	Soil	
IM4	Sea or brackish water + CP	

Additional corrosion stresses to consider

- Monopile internal more likely IM4 than IM2
- Microbially induced corrosion (MIC)
- Input into fatigue considerations



Some additional coating stresses to consider



Impact and abrasion

- Mechanical damage during installation
- Secondary steel in boat landing area

Biofouling

- Secondary and primary steel in tidal zone

UV degradation

- TP's / jackets prior to installation
- Degradation in service / navigational requirements

Electrical

- Additional CP requirements

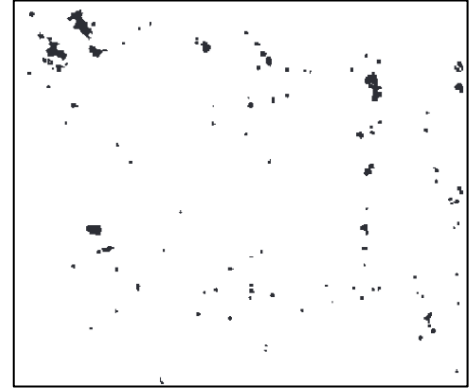
Corrosion categories

Reconciling different guidance's on environmental classifications

VGB / BAM 021 Parts 1-4	DNV GL RP 0416	NORSOK-M501 Edition 6	ISO 12944 – 2
Corrosion protection for offshore wind structures	Corrosion protection for wind turbines	Surface preparation and protective coating	Corrosion protection of steel structures by protective paint systems
Corrosion	Corrosion	Coating	Coating
1 - Atmospheric Internal	Atmospheric Zone	A.8 - Structural carbon steel , 80C in internal dry and ventilated areas	C4 - High corrosion
2 - Atmospheric External		A.1 - Structural steel < 120C	CX (Offshore)
3 - Splash zone / tidal zone / low water zone	Splash zone	A.7A - Carbon and stainless steel in the splash zone	Splash and tidal zones CX (Offshore) and IM4
4 - Underwater zone	Submerged zone (includes buried zone)	A.7B - Submerged carbon and stainless steel < 50C	IM4

Corrosion categories

Anticipated design lives not adequately covered by protective coatings testing



Major maintenance is loosely defined as 10% of the structure or part of the structure to Ri3 (ISO 4628-3) →

Durability – Expected life of a protective paint system to first major maintenance

- Low (L) up to 7 years
- Medium (M) 7 to 15 years
- High (H) 15 to 25 years
- Very High (VH) > 25 years

Corrosion classification	Durability as per ISO 12944-1			
	Low	Medium	High	Very High
C4	✓	✓	✓	✓
C5	✓	✓	✓	✓
CX	-	-	✓	-
IM2	-	-	✓	✓
IM3	-	-	✓	✓
IM4	-	-	✓	-

Corrosion control options

How different corrosion control options interact with coatings and some knowledge gaps



- Most coating knowledge comes from carbon steel substrates
- Less guidance for other substrates TSA / TSZ, aluminium, etc



- Coating useful life is a key factor (per DNV GL RP0416)

$$CA = V_{CORR} * (T_D - T_C)$$

CA = corrosion allowance, V_{CORR} = corrosion rate, T_D = design life of structure, T_C = usable life of coating



- Wide range of cathodic disbondment tests
- Lack of systematic evaluation (vs. potential)
- Coating degradation factors have a large impact on CP design



- Mixed early results (secondary factors)
- What is a realistic “useful life”?
- What constitutes an optimal coating system?

Material selection

Limited guidance on areas other than carbon steel

- Carbon steel key focus in guidance
- Increased focus on metallic coatings
 - Increase design life
 - Reduced corrosion allowance and CP requirement
 - Overcoating limitations e.g. colour
- Non-carbon steel is often covered within OEM or secondary steel
- No dedicated pre-qualification criteria
- Impact of thick films on TSA

VGB / BAM 021 Parts 1 - 4	DNV GP RP 0416	NORSOK- M501 Edition 6	ISO 12944 – Parts 5 and 9
HDG and TSZ for secondary steel covered.	Specific reference to fasteners. 6.2.3. Hot dip galvanising included	A.2A Thermally sprayed aluminium. A.2B Thermally sprayed zinc. A.6A Aluminium A.6B Hot dip galvanising	Table B3 Hot dip galvanised steel (excludes CX) Table B4 Thermally sprayed metallic coatings ISO 12944-9 (CX) only addresses organic coatings

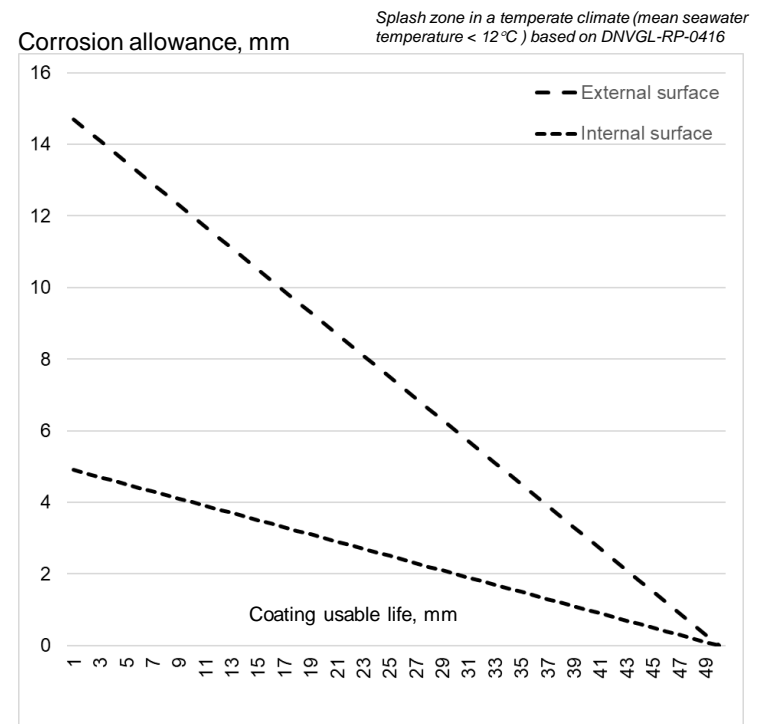
Corrosion allowance

Increasing confidence in useful life could possibly assist in reducing corrosion allowance.

$$CA = V_{CORR} * (T_D - T_C)$$

V_{CORR} = expected maximum corrosion rate
 T_D = design life of structure
 T_C = design useful life of the coating

- Confidence in T_C and V_{CORR}
- T_C only usable to 15-25 years for splash zone and immersed (assuming IM4)
- Practical T_C (experience) ~ 20 years
- Formulation continuity / innovation challenge



Protective coatings

Guidance is largely aligned but care should be taken when comparing different standards on coatings

Corrosion stress zone	VGB / BAM 021	DNVGL-RP-B401	NORSOK-M501 Edition 6	ISO 12944 – 9 (Zone 1 from Part 5)	ISO 24656 : 2022
1 - Atmospheric Internal	NOC=2 DFT=300 EP	I MNOC = 1 DFT >20 II MNOC=1 >250 III MNOC=2 >350	A.8 MNOC=1/2 DFT=150/85 EP	C4 MNOC=2 DFT=200 EP,PUR,ESI	DNVGL-RP-B401 with additional IV MNOC=2 DFT>600 EP V MNOC=2 >1000 EP,PO
2 - Atmospheric External	MNOC =3 DFT=360 EP+PUR		A.1 MNOC=3 DFT= > 280 EP+PUR	CX MNOC=3 DFT> 280	
3 - Splash zone / tidal zone / low water zone	MNOC = 2 DFT=600 EP+PUR		A.7A MNOC=2 DFT=>600 EP (+PUR), PO	CX/IM4 MNOC=2 DFT> 600	
4 - Underwater zone	MNOC =1 DFT= 600 EP		A.7B MNOC=2 DFT> 350 EP	IM4 MNOC=2 DFT> 350	

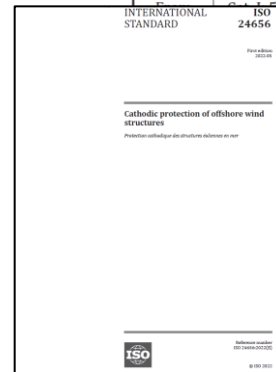
Cathodic protection

More information is required to allow the determination of accurate coating breakdown factors

- ISO 24656: 2021 – Annex D
- Indicative coating breakdown factors
- Variance to DNV-GL-RP-B401
 - different coating systems added (IV and V)
 - different coating breakdown factors
- Limited real-life studies
 - Lower f_{CFINAL}
 - Higher anode consumption
- Impact of electrical conductance due to seawater uptake

$$f_{CFINAL} = f_{CINITIAL} + t \cdot c$$

Coating category			I	II	III	IV	V	I	II	III	IV	V
Zone	Initial after coating	Initial after installation	Annual breakdown rate for surfaces exposed to free-flowing seawater					Annual breakdown rate for surfaces within confined spaces not exposed to free-flowing seawater				
	a %	b %	c %/year					c %/year				
FWZ ₅₀ % to FWZ ₅ %	Cat. III 1,0 Cat. IV: 0,75 Cat. V 0,5	Cat. III 1,0 Cat. IV: 0,75 Cat. V 0,5	NA	NA	1,5	0,8	0,6	NA	NA	1,5	0,8	0,6
	Cat. I 5,0 Cat. II 2,5 Cat. III 1,0 Cat. IV: 0,75 Cat. V 0,5	Cat. I 5,0 Cat. II 2,5 Cat. III 1,0 Cat. IV: 0,75 Cat. V 0,5	10	2,5	1,2	0,6	0,4	5	1,5	0,8	0,4	0,3

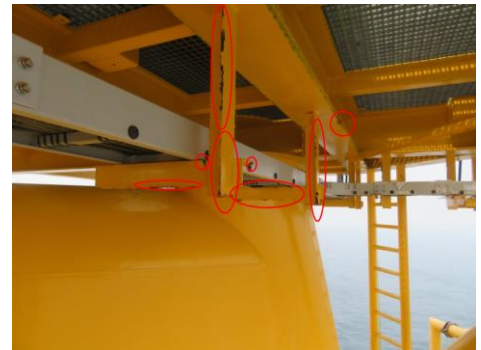


Excerpt from ISO 24656 : 2022

Secondary factors

Some additional factors influencing the usable coating life.

- **Correct specification & coating selection**
 - Incorrect specification/lack of knowledge to assess testing
 - Focus on minimum acceptable not optimal performance
- **Installation**
 - See far too many defects
 - Impacts design and operation
- **Lack of performance feedback (breakdown factors)**
 - Not structured
 - Limited to visual only
 - Sits within owner operators/ not coating vendors
- **Lack of pre-qualification tests for a longer design life**
 - Amendment to ISO 12944-9
 - Suitability of lab based pre-qualification testing
 - More knowledge on relevant coating performance
 - Structured evaluation versus electrical potential



Summary & improvements

- Specification transition largely successful!
- Guidance documents generally aligned - room for improvement
- More synergy / understanding between corrosion protection options needed
- Confidence in coating usable life is key
 - confidence is increasing – requires more structured feedback



Paper 7 – Malcolm Morris





Bio – Malcolm Morris



Malcolm Morris is a technical manager with the Protective & Marine Coatings division of Sherwin-Williams (Formerly Leigh's Paints). Malcolm started as a chemist with Leigh's 1978, with a career based mainly in R&D and technical service; but has taken on a broad role in supporting technical and commercial colleagues within the business, as well as customer facing technical support and training. He has active involvement with CEPE Protective Coatings groups, the British Coatings Federation and sits on several British and ISO standards committees. Malcolm is a chartered scientist, fellowship professional member of ICorr, fellowship member of The Oil & Colour Chemists Association, and a NACE Level 3 coatings inspector.



Update on ISO TC35 Meetings, June 2022

February 2023

Malcolm Morris – Sherwin Williams P&M Coatings

Coatings Standards Hierarchy

Interchange of information up and down the chain...

ISO Technical Committee (TC35 - paint & varnish) PUBLISH STANDARD

ISO Sub Committee (SC9 / SC12 / SC14 etc) RESOLUTIONS to TC

ISO Working Groups DEVISE, REVISE, DRAFT & RECOMMEND to SC

National Mirror Committees (BSI STI/21, STI/10) DISTRIBUTE / REVIEW

Industry Trade Associations (BCF / CEPE/ MPF etc) REVIEW

Professional Bodies (RSC / ICorr, etc) REVIEW

Individual industry members / public consultation REVIEW

Overview

TC35/SC12/WG2 – Surface preparation standards

TC35/SC12/WG3 – Surface preparation methods

TC35/SC12/WG4 – Surface preparation media

TC35/SC14/WG12 – Revision of ISO 12944

TC35/TC67/JWG 6 – Harmonised standards for coatings inspector & applicator qualifications / competence

TC35/SC12/WG2 – Surface preparation standards

ISO 8501-1 (Also 8501-2) – Visual assessment of surface cleanliness

- New text developed and discussed at our last meeting.
- Reviewed and tweaked by various UK technical committees
- Submitted as official UK comment
- Headline - UK text accepted for inclusion into first committee draft for revision of ISO 8501-1 
- Still to be debated and possibly amended but we're in at the ground floor

TC35/SC12/WG2 – Surface preparation standards

Other proposed amendments to ISO8501-1

- General opinion **not to change existing Sa photographs**
- Proposed to split photos into an informative annex as they are generally not used in the field – only as training guidance examples or in cases of conflict
- Have the text and verbal descriptions as the main standard – This would make it digitally available instead of the expensive printed book – Also make revisions quicker and cheaper to users.
- New photographs only required for proposed new surface prep grades
- Informative pictures could be high quality digital images rather than expensive printing process photographs – Again reduce cost and enable PC/ mobile device access

TC35/SC12/WG2 – Surface preparation standards

Other proposed amendments to ISO8501-1

- Existing St2 & St3 standards to be limited to manual preparation methods only
- New categories for mechanical power tool cleaning proposed
 - Me2 – Thorough power tool cleaning to near white metal
 - Me3 – Very thorough power tool cleaning to white metal with surface profile
- Wording for these categories in the initial draft will be based around UK proposals (which were initiated by our committee)
- Aiming to meet the requirements of a standard achievable by modern mechanical preparation tools

TC35/SC12/WG2 – Surface preparation standards

ISO 8501-3 – Visual standard of surface cleanliness (Pre-blast)

- Working draft under consideration
- Better diagrams to illustrate surface defects (porosity, laminations etc)
- Informative photographic annex to display more common defects
- Introduction of a comparator to give a tactile demonstration of surface defects was rejected

ISO/TC 35/SC 12/WG 3 “Surface preparation methods”

PWI - ISO 8504-6 Laser cleaning methods

- Chinese initiative. First draft prepared but more detail needed.
- WG3 experts to gather more information
- Possibly be issued as a ISO TR rather than a standard (initially)
- Also there is a US (AMPP) document on laser cleaning that is more advanced than the ISO work
- Possibility of some collaborative work between ISO and AMPP

ISO/TC 35/SC 12/WG 3 “Surface preparation methods”

- ISO 8504-5 – Water-jetting methods – Now at FDIS ballot stage

ISO/TC 35/SC 12/WG 4 “Blast Cleaning abrasives”

- Standards under discussion including encapsulated abrasives – project on hold until method for determining emissions can be agreed.
- New proposals for high chromium cast iron grit and stainless steel shot abrasive media

ISO/TC 35/67 JWG 6

Standards for Harmonized Competence of Coatings Inspectors and Coating Applicators

Two separate working groups for each field

Scope set out to provide a level playing field for training and experience requirements at the various levels of inspector and applicator

Management system requirements of each scheme to be compliant with ISO 17024

Equivalence tables being drafted to compare syllabus & experience requirements between ICorr / AMPP / FROSIO etc (For inspectors)

Fewer established options for applicators. Harmonized list being compiled, input from ACQPA / ICATS / Train the Painter etc will be invaluable

TC35/SC14/WG12 – Protective Paint Systems

SC14/WG12 set up to review and revise ISO 12944

Part 9 Offshore structures 'CX' has been moved into parts 5 and 6, such that CX will be a more natural progression from C1 – C5

Many (hundreds) comments received – Review and consideration will take several ZOOM meetings

Japanese proposal for a standard for Fluoropolymer coatings – Likely to be driven as an ISO TR initially

Danish proposal for a new standard for corrosion protection for offshore wind turbines. Extensive discussions (Standard or TR ?)

Likely to be developed as a joint working group with ISO/TC156 (Corrosion of metals and alloys) to include a holistic corrosion protection package including cathodic protection, for extreme high durability offshore



Q and A Session



President - Closing Remarks and Thank You's



Event Photos

Chambers Venue - 1



Chambers Venue - 2



Networking – In the Galleries



Networking – Coffee in the Chamberlain Room



Networking – Lunch in the Chamberlain Room



Networking – 3, (with our Exhibitors – AMCASH (UOB), SAFINAH Group and CORRPRO).



Presentations – 1, (Prof. Alison Davenport – Pitting: The delicate balance between Dissolution and Passivation.



Presentations – 2, George Winning – Production Chemistry for Corrosion Engineers - PC4CE (New ICorr Training Course).



Presentations – 3, (Simon Daly – Challenges for Selecting Coatings for the Fixed and Floating Offshore Wind Industry).



Presentations – 4, (Special Award to Winston Shepherd for Industry and Standards Contributions).

