MIC

Microbiologically induced corrosion in cold systems at Forsmark NPP

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The utilization of Fe(II) as an electron donor makes iron oxidizing bacteria to
strong analog organisms for any potential life that could be found on Mars.

MIC: an underestimated degradation mechanism

- 20% of all corrosion damage is estimated to be caused by MIC
- Yet the degradation mechanism has officially been recognised only recently (NACE, 1990)
- MIC differs från other types of local corrosion damage in terms of attack patterns, propagation, degradation speed, effects on mechanical integrity, counteractions and recidivity
- Lack of systematic characterization of different MIC-phenomena makes it difficult to predict damage tollerance of mechanical components in specific cases
- Improved characterization and understanding of MIC-phenomena is directly relevant to the optimization of the maintenance program at FKA

MIC in the cooling water system for the turbin

Voluminous tubercles, but minimal amount of material degradation. The tubercles developes in shelted places, on painted carbon steel. The distribution pattern on equivalent places appear to be random, although there is a tendency for the tubercles to develope in colonies

Soft, well defined forms

A thin outer layer covers the tubercles. On the inside the body is spongelike, soft and friable. If powdered it shows an intensive yellow ochre color. This type of MIC bacteria metabolize probably both organic matter and iron ions. The rate of material degradation is so low that it is not expected to affect the mechanical integrity of the components under their designed life time.

At a closer look many other interesting features are disclosed

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MIC displays different habits on different materials

On the flat surfaces of super duplex cast steel are found small, individual tubercles with hard shell and spongelike core which is partially green colored. They do not cause any significant level of material degradation

Element	Wt%	Wt% Sigma
C	6,08	0,79
O	32,82	0,89
Si	0,7	0,11
S	4,75	0,62
Cl	0,82	0,17
Cr	37,64	1,12
Mo	17,19	1,52
Total:	100	

A third type of tubercles

Within the shelted gaps between the flanges inside the pump house are found well shaped tubercles with well defined canals for exchange between the inside and the outside environment. The base material is painted carbon steel.

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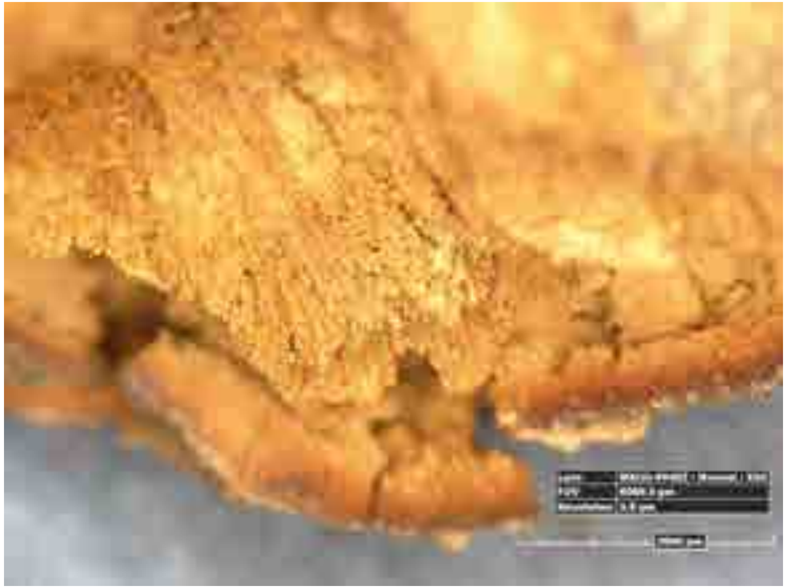
Well defined features

The tubercles display some remarcably regular features. The inside is hollow, with walls that in some parts display uniform thickness, which appear to be defined by a dark, smooth and perfectly adherent film.

Canals and growth directions

Orifices appear on the top of the inside dome. The spongelike core has distinct growth directions. Different structural levels can be identified by different color nuances.



MIC in the fire protection system

A more aggressive type of MIC is encountered in the open tanks of the fire protection system. Here we find distinct, big tubercles which appear to be randomly distributed, although preferentially on shelted places. The form of the tubercles is often elongated, like big slugs, and can protude well beyond the solid support on which they stand. The base material is painted carbon steel. The environment is industrial water.

Protuding tubercles

The tubercles may develop and protude well beyond the metal surface from which they assume their building material. The feature is suggestive of an advanced transport system supporting the metabolism of the tubercles.

Deposits of black and soft iron(II)-compounds

The degradation of the base material is concentrated on a limited spot under the body of the tubercle. The material damage is significant. At the bottom of the corrosion holes are found deposits of black and soft iron(II)-compounds.The size of the corrosion holes appear to be related to how big the tubercles are. The dark holes are probably colonized by sulphur reducing bacteria, SRB, which ”dig out” iron(II) ions from the base material. Those ions are then metabolized by the iron oxidizing bacteria which build up the red body of the tubercles.

A big hanging ”slug” digged a deep corrosion hole

This remarcably clinging specimen has digged a 5mm deep hole on top of its support

Some solitary specimens

A big, elongated tubercle in a solitary position far away on a pipe wall. And a small tubercle on a screw head

Complex structure

An ordered pattern of thin magnetite walls builds up a complex system of adjacent cells

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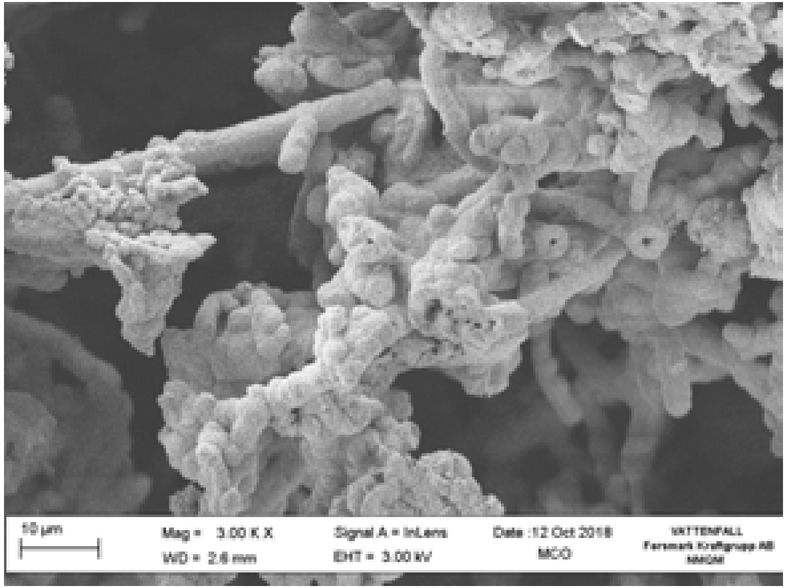
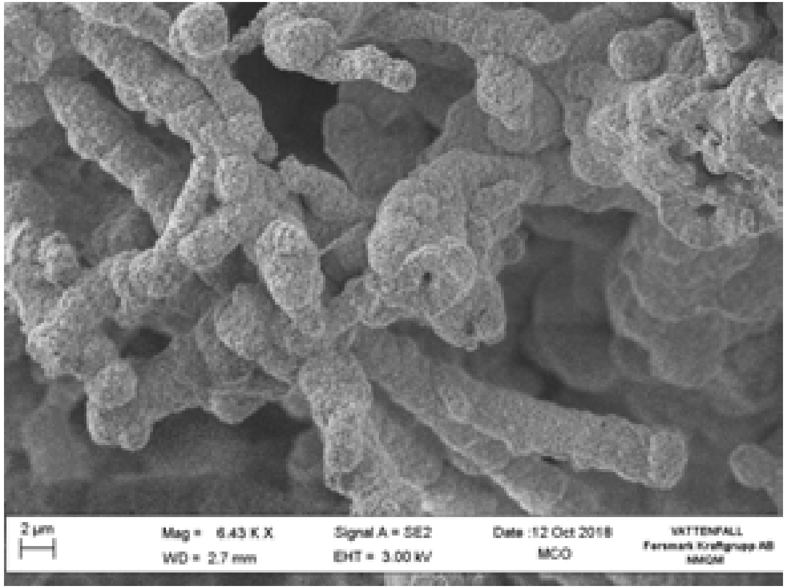
Biogenerated iron(III)oxide-structures

In the scanning electron microscope the biogenerated features of the corrosion tubercles are displayed in an astonishing richness of details





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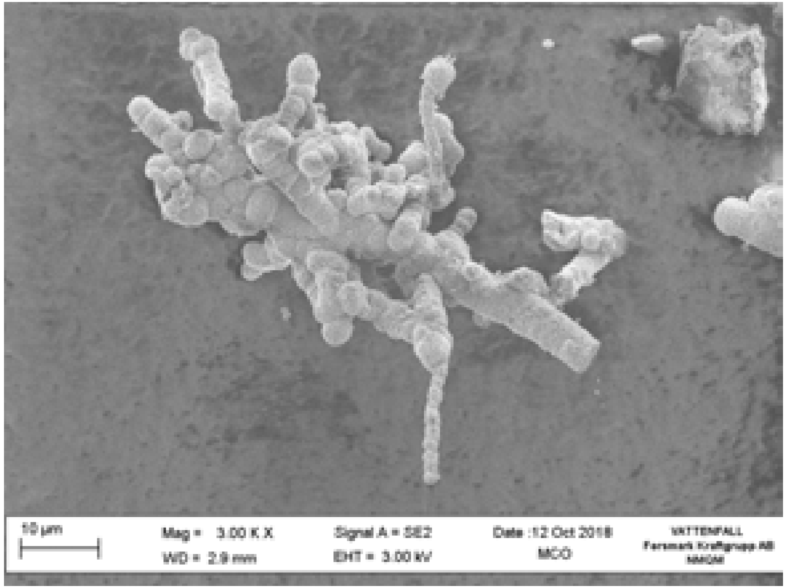
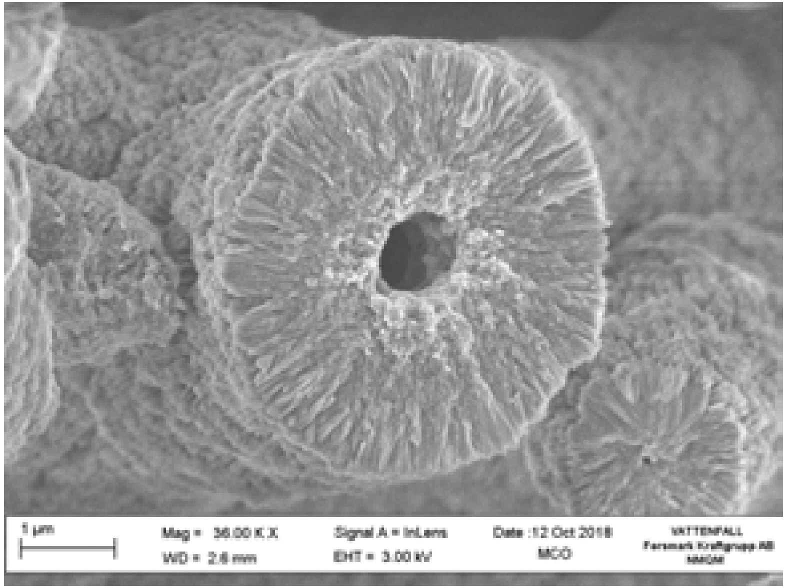
Hollow microtubes

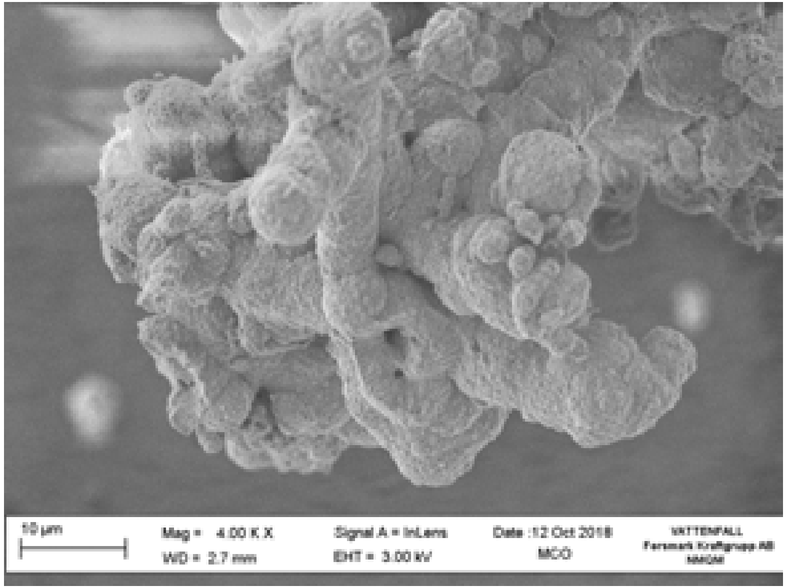
The spongelike core material of the tubercles is build up by an intricate network of hollow microtubes. Iron(III)-oxide is crystallised radially around the bacteria in the process building up the microtubes

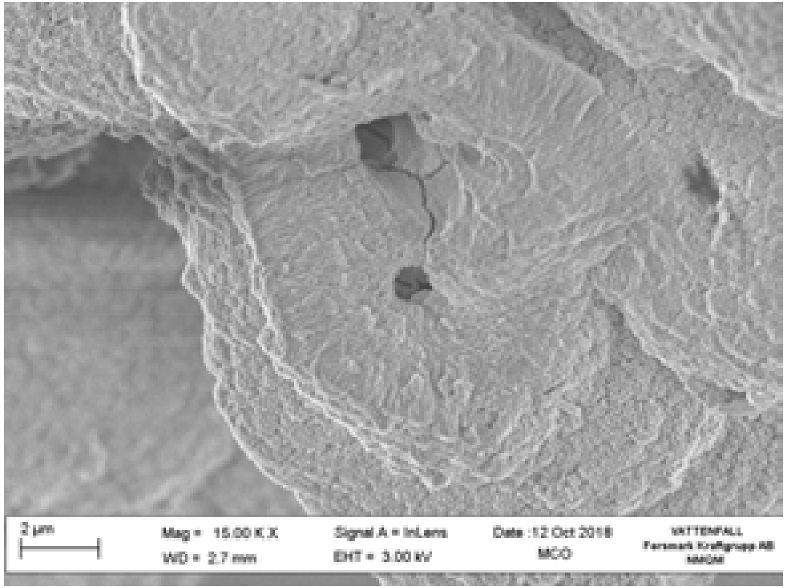




Biomineralization

The iron oxidizing bacteria take up the energy contained in the metal and return it to a mineral compound





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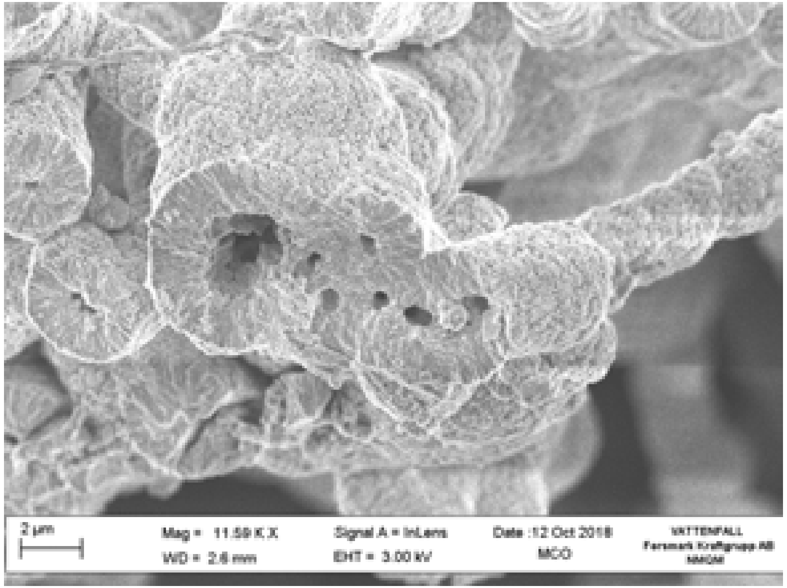
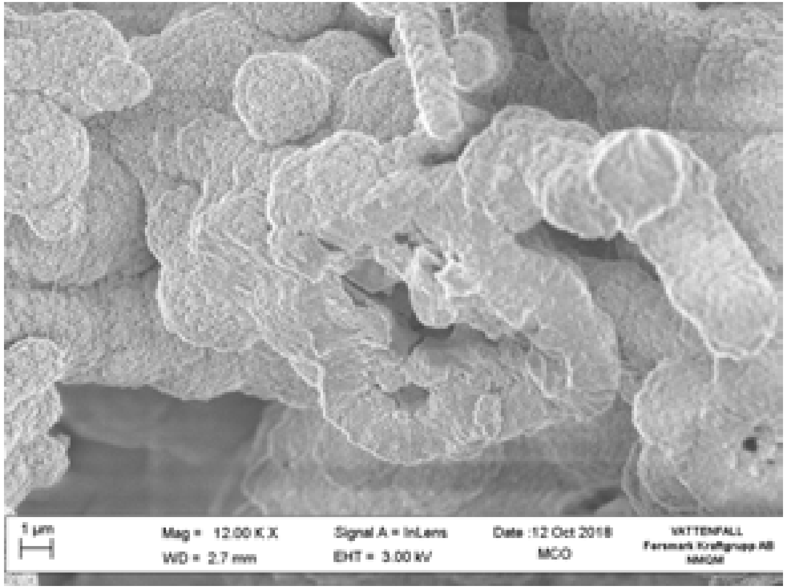
Life is way of sustaining energy dissipation

By buildning up complex solid structures the bacteria obtain a selfsustaining dynamic system which optimize the flow of metabolites and maximize the energy uptake from the base material. That’s way MIC may results in substantially higher degradation rates as compared to trivial cases of pure electrochemical corrosion.

LIFE IS AN ORDERED WAY OF PRODUCING DISORDER





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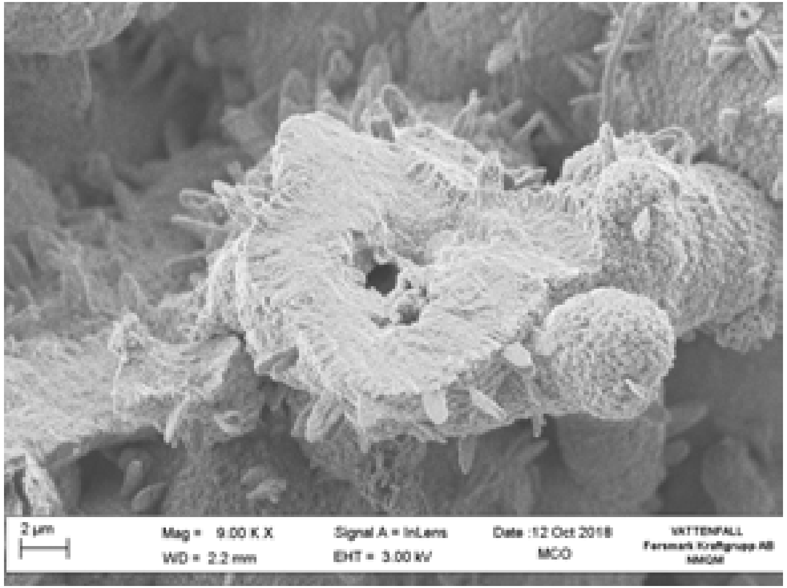
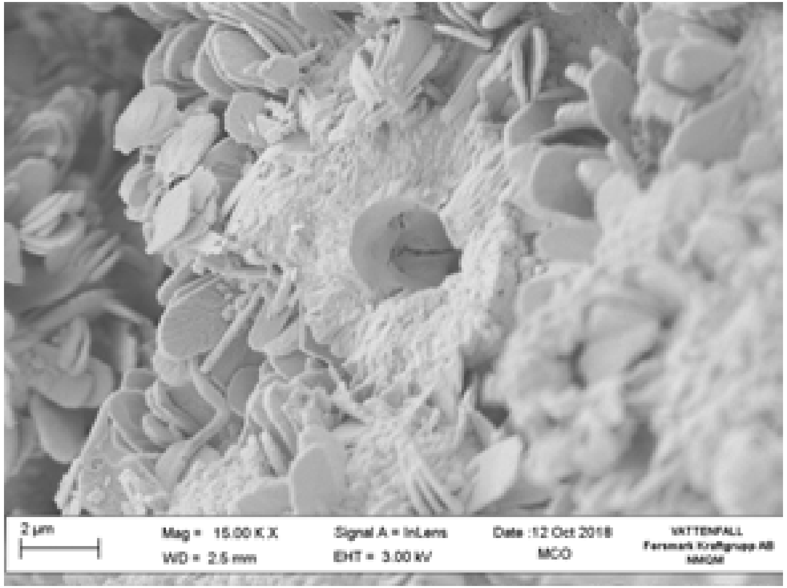
Different features - different functionality

In same regions the microtubes are equipped with small plates





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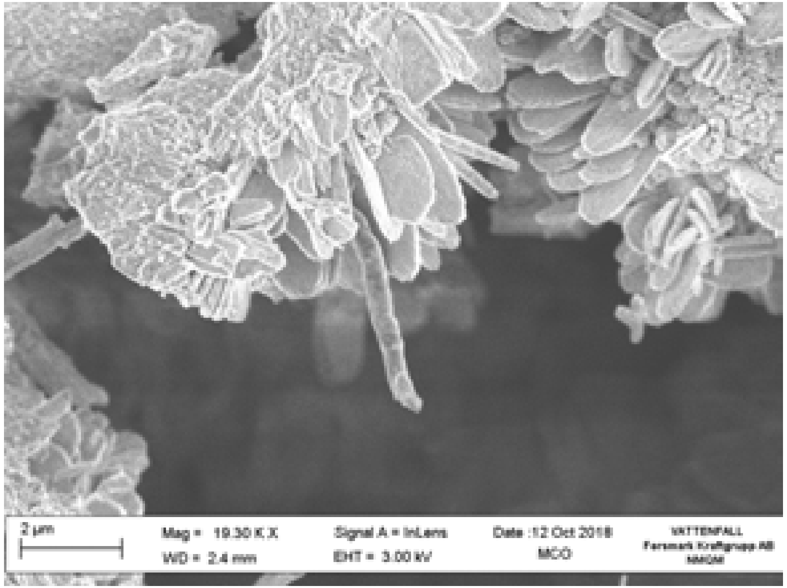
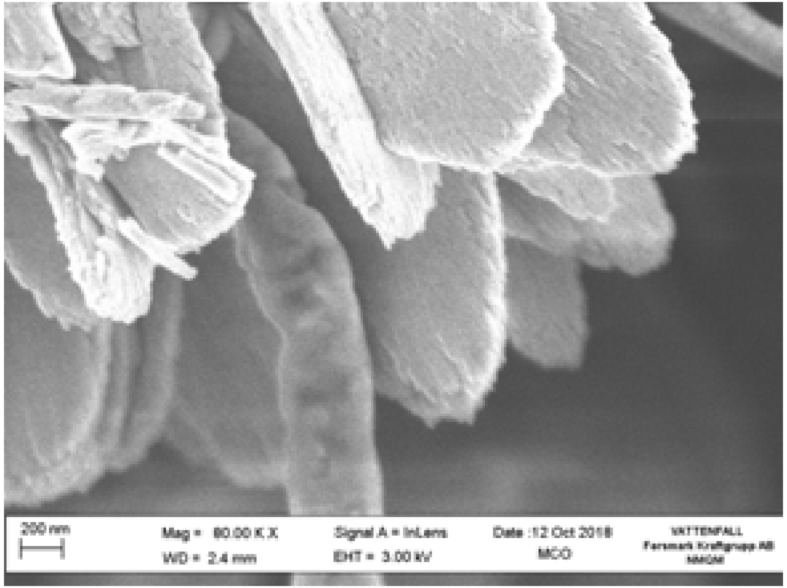
Iron oxidizing bacteria

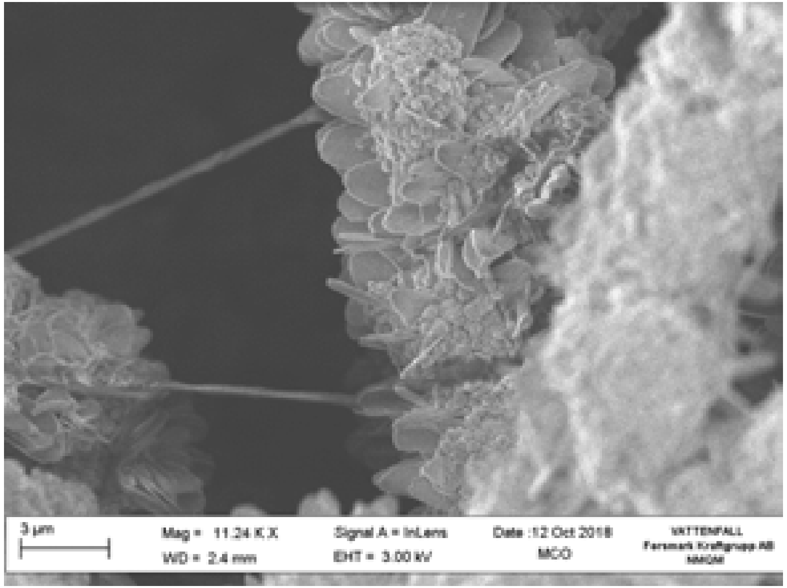
The pictures below catch a bacteria emerging from in between a group of plates

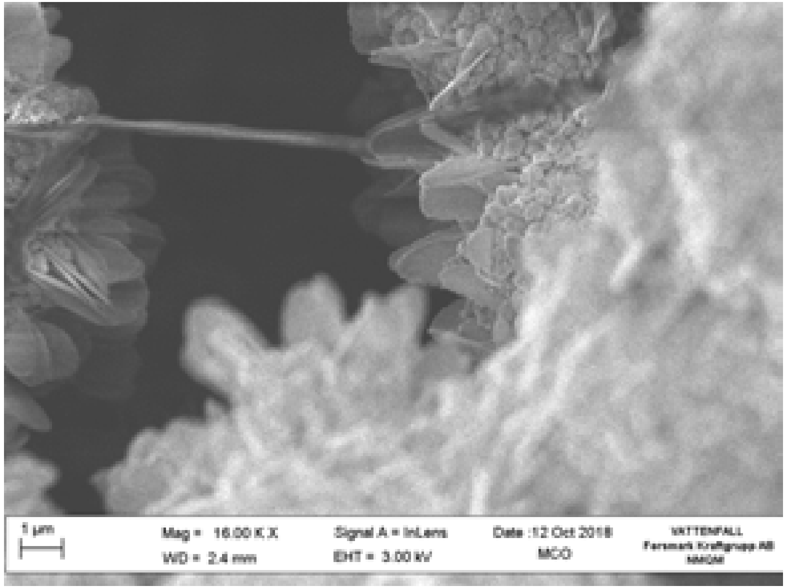




Bacteria

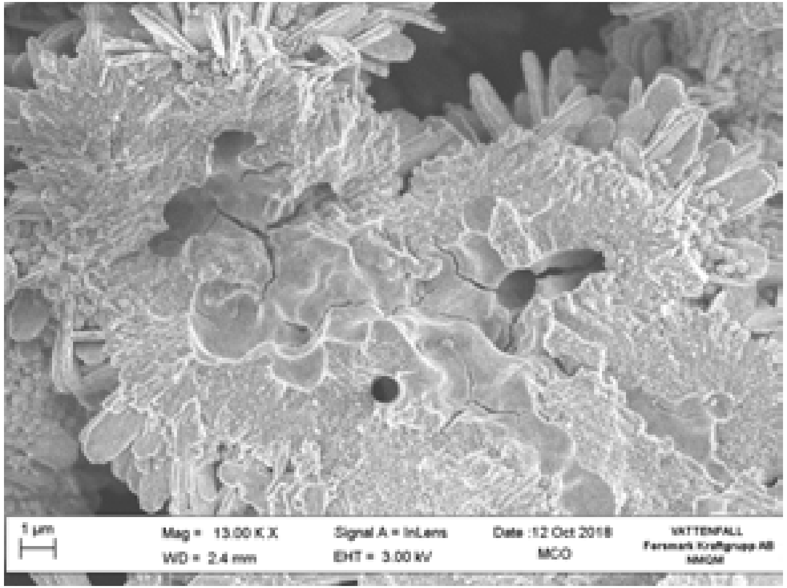
Bacteria elongating from in between a group of plates on a microtube to the microtube next by. What’s going on?

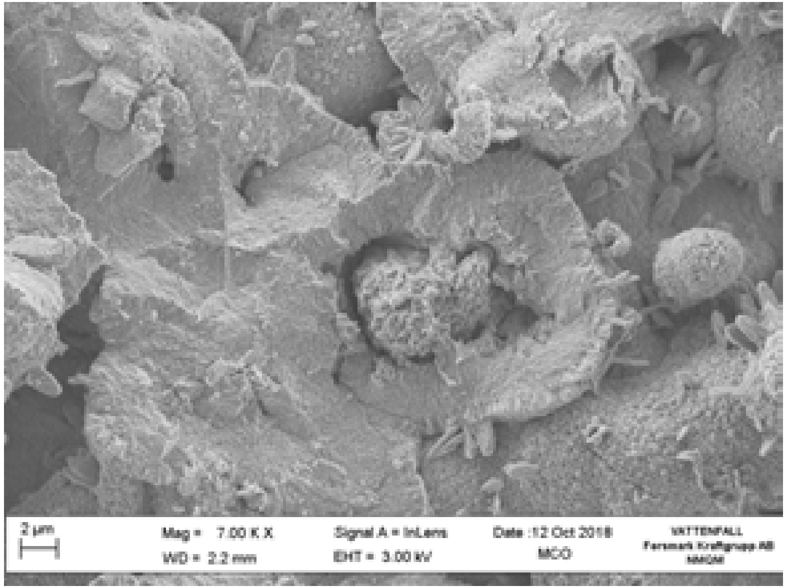




Further features yet to be understood

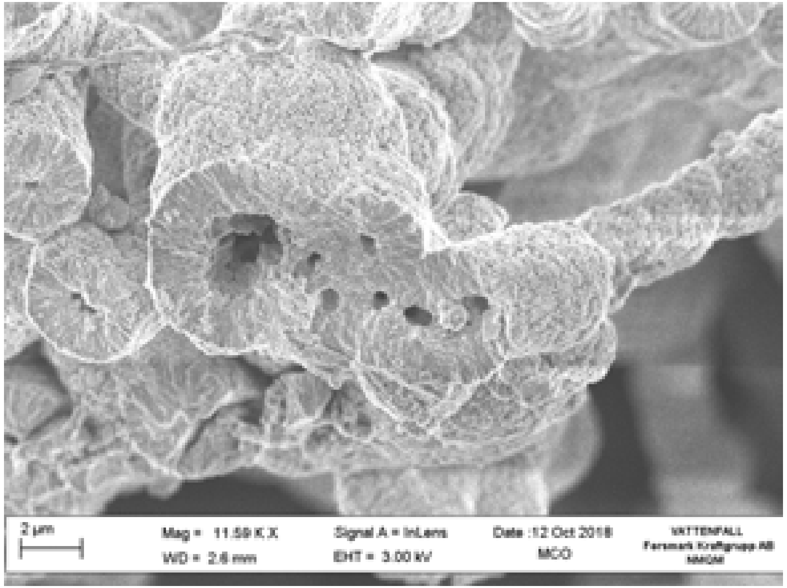
Deep buried into a system of merging hollows is observed a porous structure. The richness of features observed gives clues to a complex biological system yet to be understood

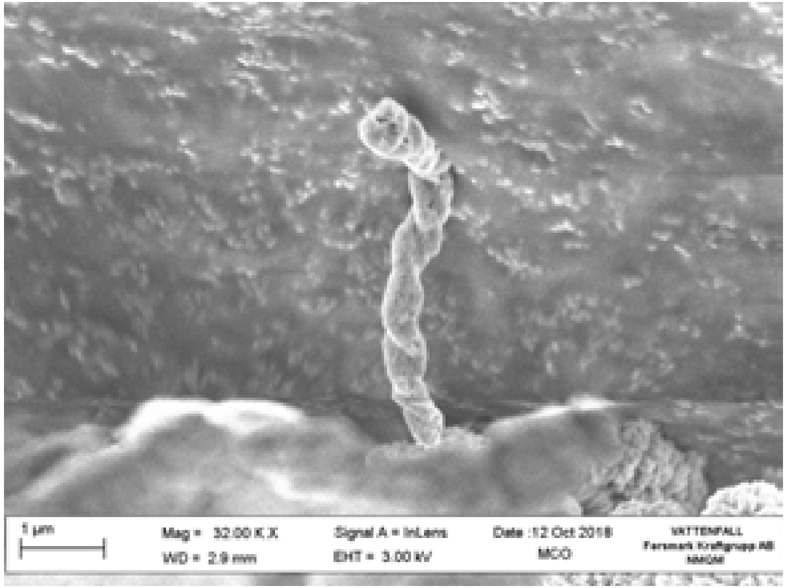




MIC diagnosis

The twisted shape of the bacteria catched in the right picture suggests that it may belong to the iron oxidizing species Gallionella Ferruginea





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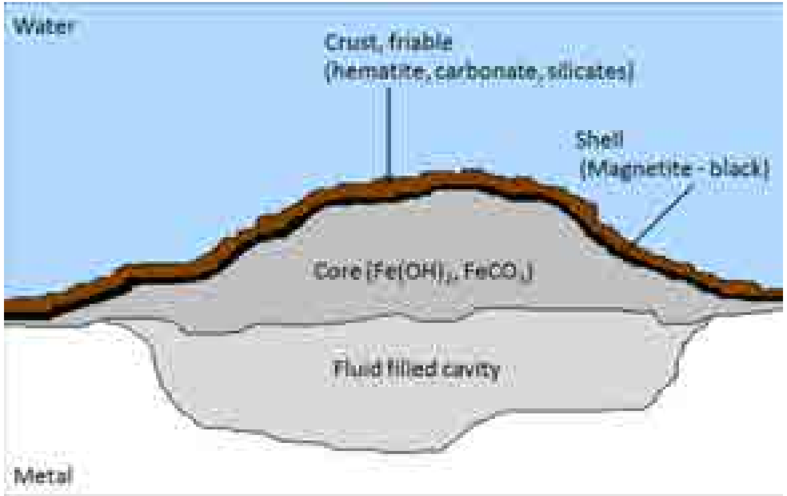
Some summarizing remarks

- MIC-tubercles display a high level of structural organization, as compared to the simple model used to describe tubercle formation by pure electrochemical theory.
- A richness of morphological features calls for better characterization and understanding
- Diagnosys, damage prediction and proper countermeasures may be much improved by learning more about the phenomena.

Electrochemical model for corrosion tubercle



Engineering challenges

In order to be able to predict the impact of MIC on the systems we need to be able to quantify the extent of MIC-damage in a rational and reproducible way

In the coming years Forsmark will carry out both extensive inspections of the fire protection system and discrete sampling for in depth charachterization

Inspection systems need to be able to:

- identify the degradation mechanism
- quantify parameters related to the number and size of both the tubercles and the max deptht of the corrosion holes

.

The pressurized part of the fire protection system

Out in the tube system the water pressure rises to 20 bar and the oxygen level becomes much lower then in the open tanks. The base material is galvanised steel. Here the MIC tubercles take on a different habit: they are relatively small and homogeneous in some of their size parameters. They have hard shells and hard cores.The depth of the corrosion holes appear to be related to the hight of the tubercles.The corrosion rate appear to be constant and relatively slow..

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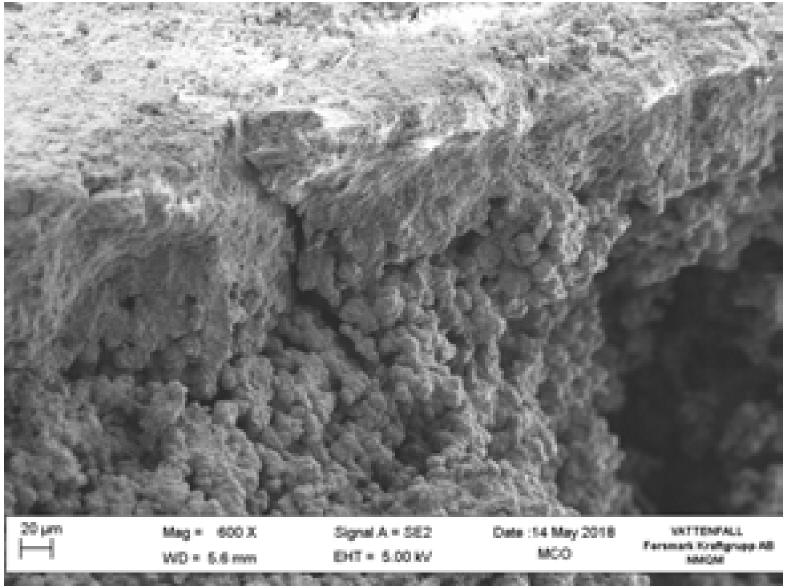
Thick shell and hard spongy core

Evidence for MIC is given by the spongy appearance of the core material of the tubercles. At higher magnification the biogenerated microtubes are clearly identified, although the picture on the ringht gives the impression of higher density and sharper angles than expected.



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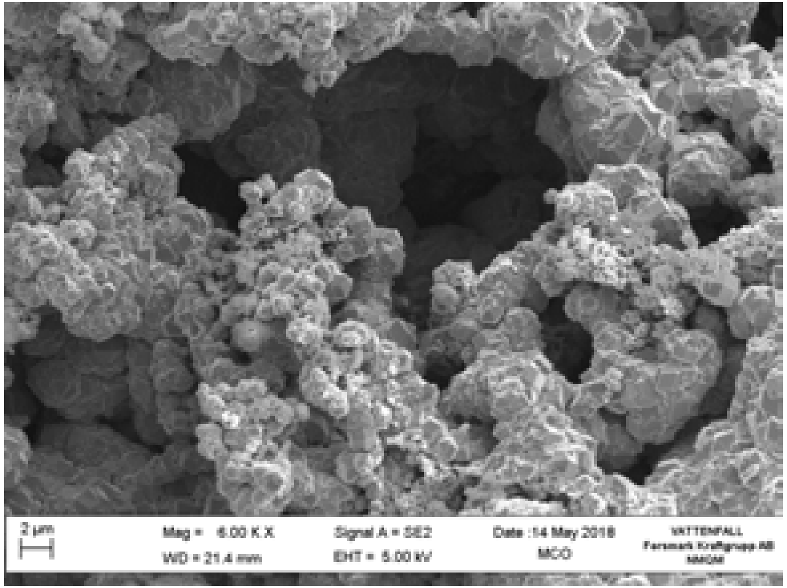
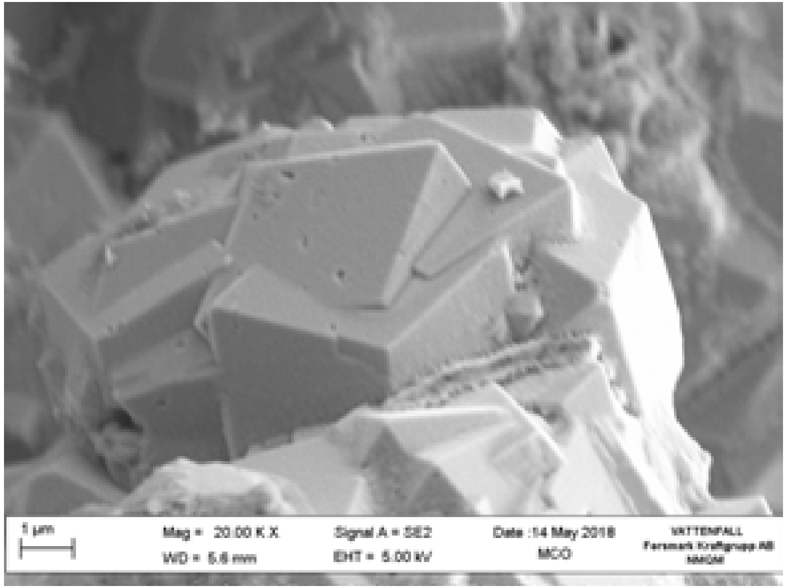
Advanced state of crystallization

At even higher magnification the microtubes look kind of fossilized.The originally biogenic Fe(III) Oxide-structures appear to have undergone a further process of mineralization.





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Inspection methods

The fire protection systems at Forsmark are quite extensive.

Which inspection methods are suited to give us a the real picture of the system's status?

- Visual
- UT
- RT

Galvanized pipe DN 50

- Detection
- Characterization
- Sizing

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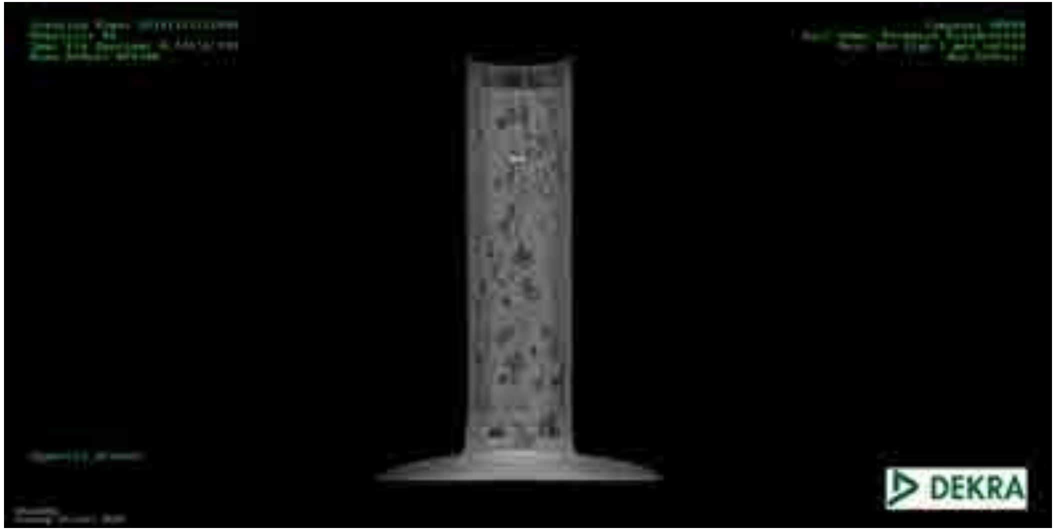
Visual

- It requires opening of the systems
- Fireprotection system **not** in operation

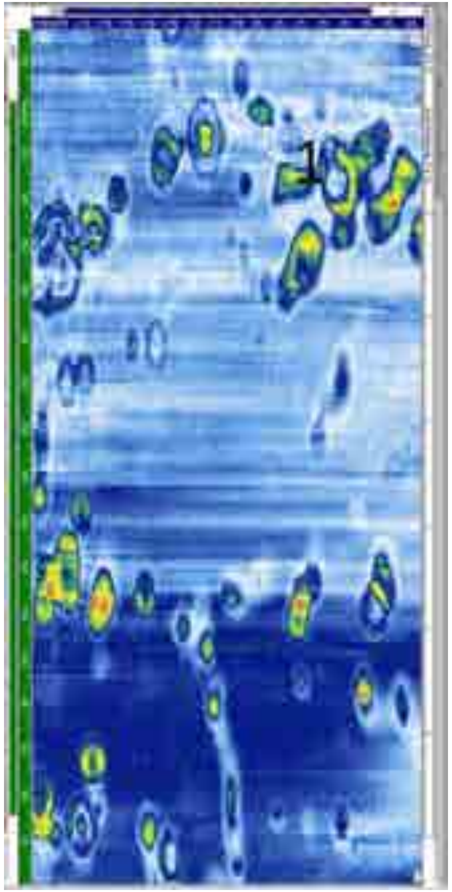
Digital x-ray

- Screen size ca 500mm
- Voltage up to 300kv
- Online evaluation
- Conventional x-ray equipment
- Need safety zone
- Ca 50-100 pictures in 8 hours

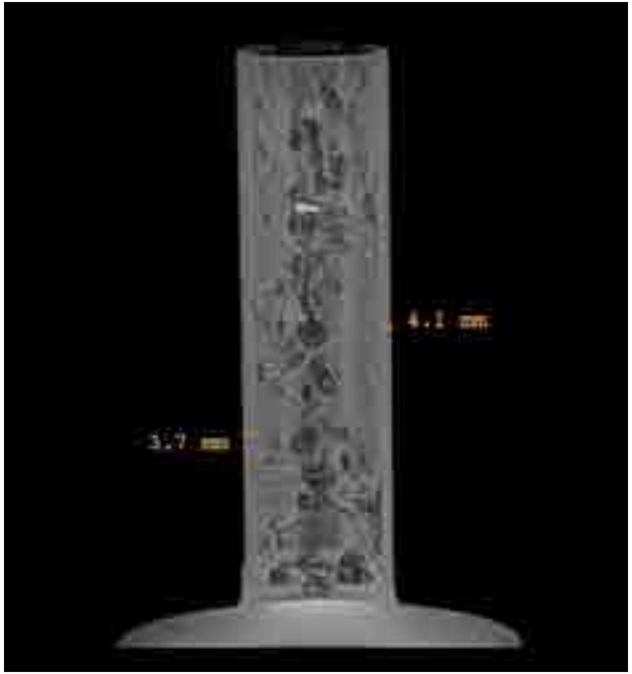


Mechanised ultrasonic Testing

- Loss of bottom eco due to scanning
- The problem could eventually be solved by using focused probe
- Small pipe diameters and thin pipe walls limit the applicability of UT



Summery



Mechanised ultrasonic testing

- It finds the defects
- It is difficult to identify the degradation mechanism

Digital x-ray

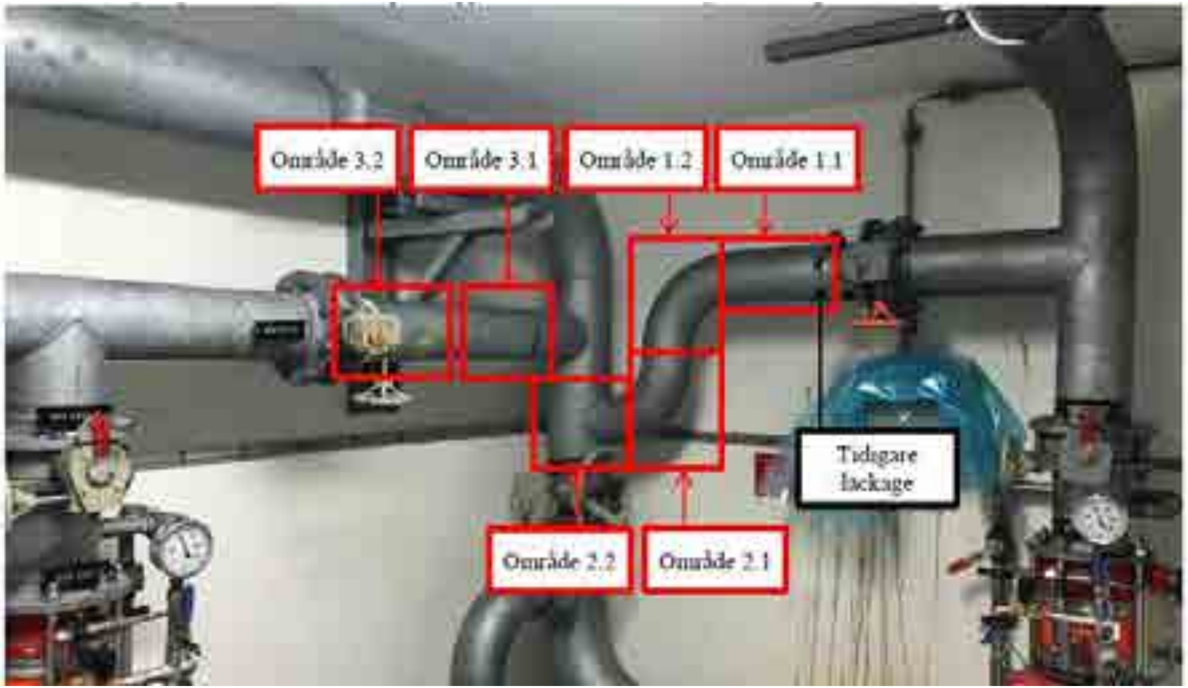
- It finds the defects
- It is possible to identify the degradation mechanism
- Quantitative measurements are possible

Visual inspection

- It requires opening of the systems
- It clearly identifies the degradation mechanism
- Needs open system

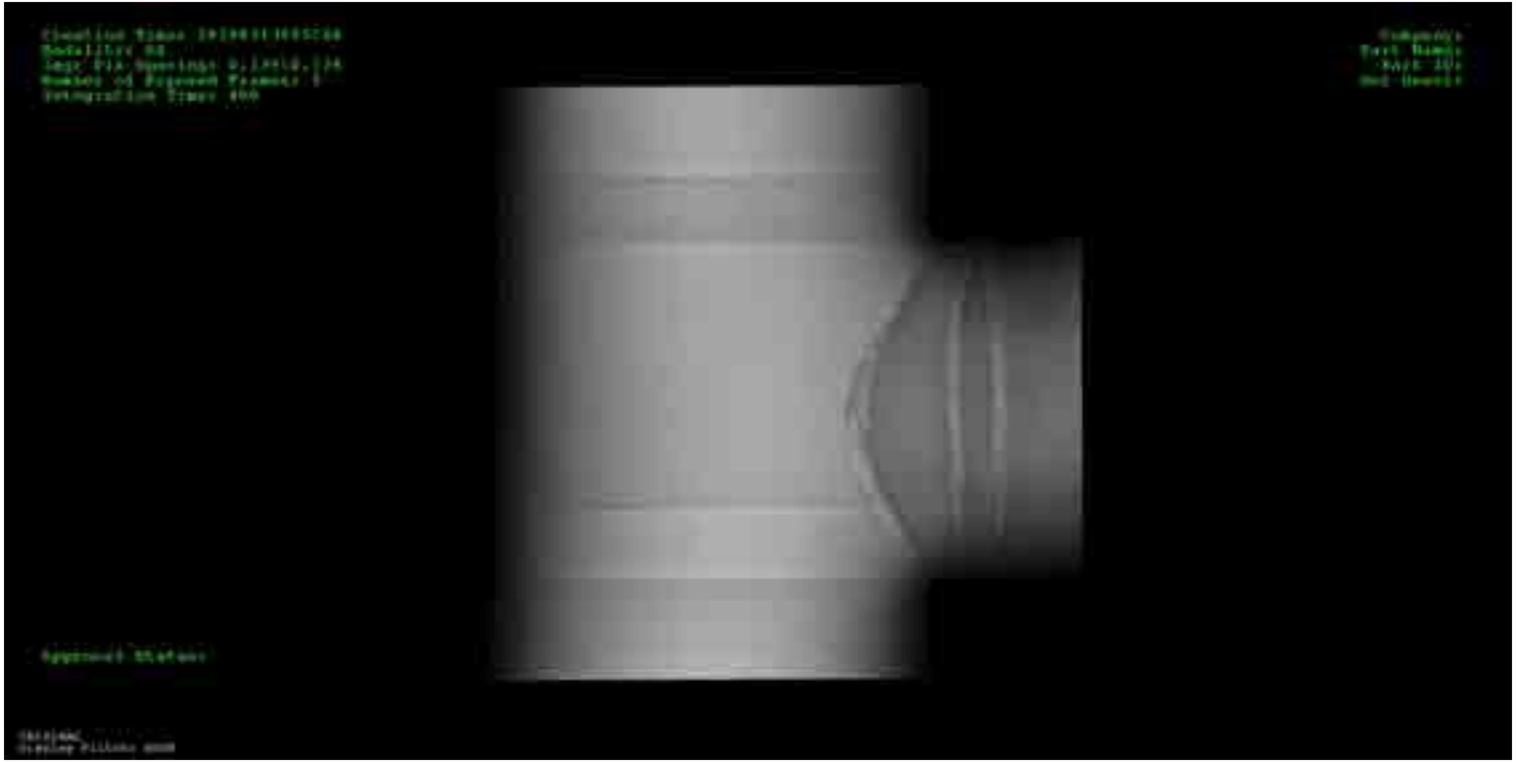
Real case 2019

- Pipe diameter 150mm to 200mm
- Waterfilled

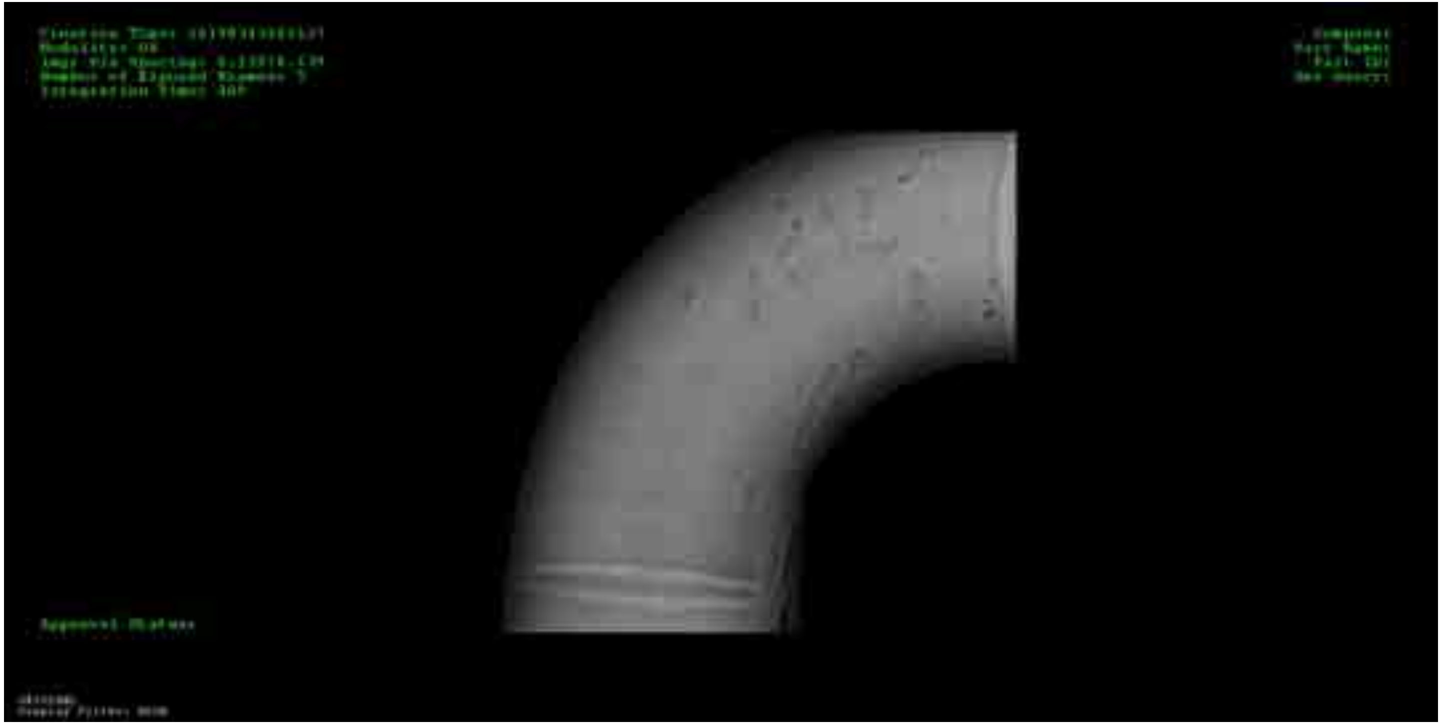


Real case 2019

Real case 2019



Real case 2019



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