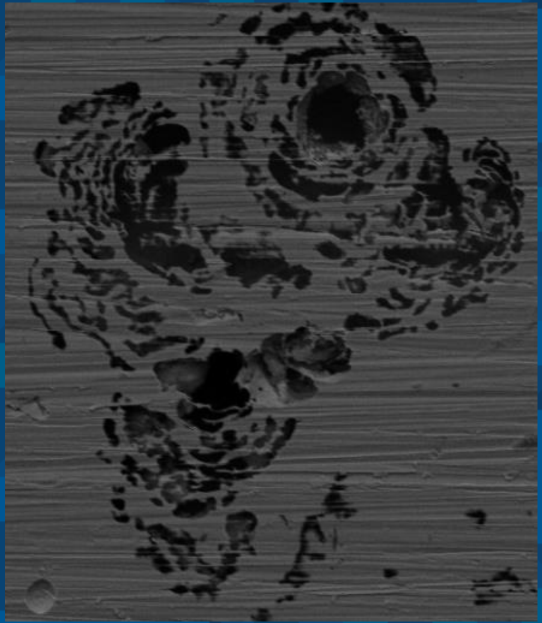
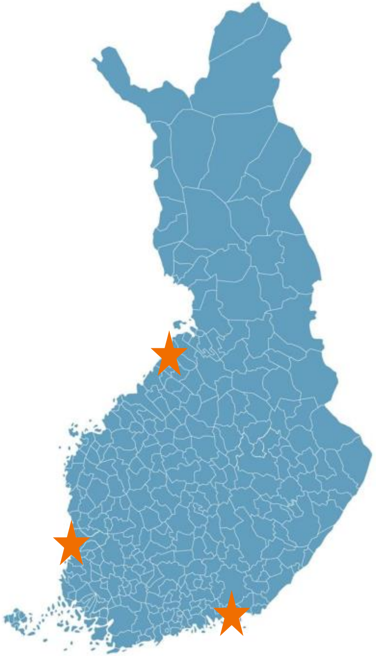


Corrosivity of different natural groundwaters from repository sites

Mervi Somervuori, Elisa Isotahdon, Maija Nuppunen-Puputti, Malin Bomberg, Leena Carpén and Pauliina Rajala

Introduction



In Finland repositories of low and intermediate-level waste

- in deep bedrock
- near the nuclear power plants
- 60 to 100 m below the ground level

Introduction

- Carbon steel containers
- Waste contains both carbon steel and stainless steel
- The containers and waste will be subjected to natural groundwater
- Groundwater always contains microorganisms
- Composition of the water depends on the origin
- Different forms of corrosion depending on the local environment

Aim of this study

- To study corrosion properties in various water conditions corresponding to each repository site
- Water composition and microbiology of natural groundwater were determined
- Corrosion properties of one carbon steel and two stainless steels were studied by electrochemical measurements

EXPERIMENTAL

Experimental set up

- Three natural groundwaters and one simulated water was studied in anoxic conditions
- The simulated water was designed to mimic the water from location C
- Water composition was analysed and the pitting index calculated
- Microbial community sizes by quantitative PCR (qPCR)
- Electrochemical measurements to define
  - Corrosion potentials
  - Corrosion rates
  - Corrosion forms
- Characterisation of the steel specimens by SEM

Water Chemistry

- Corrosion is highly dependent on water chemistry

  -> the water chemistry has important role in steel corrosion
- Chlorides and sulphates are known to cause corrosion
- Main chemical components of each water were analysed
- Physical parameters were determined
  - pH, O2, redox, conductivity
- Corrosivity of the water for carbon steel can be evaluated by calculating a pitting index
  - Value exceeding 1 predict pitting and localised corrosion

Microbiology

- Bacterial, archaeal and fungal communities were studied

- Community size by quantitative PCR (qPCR)
  - Bacterial and archaeal 16S rRNA, fungal 5.8S rRNA, sulphate reducing bacteria (*dsr*B)

- Community composition by amplicon library sequencing
  - Bacteria/archaea 16S rRNA, fungi ITS

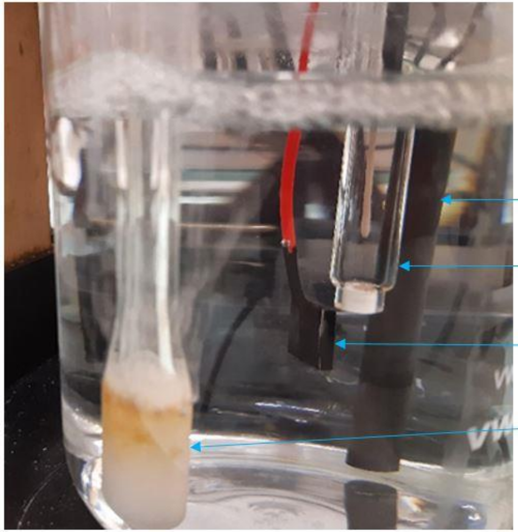
Steels used in the electrochemical measurements

- Cold-rolled low carbon steel AISI 1005 (UNS G10050)
- Two stainless steel similar to AISI 304 (UNS S30400) and AISI 316L (UNS S31603)

	C	Si	Mn	P	S	Ni	Cr	Mo	V
AISI 1005*	0.025	<0.005	0.19	0.007	0.007	0.02	0.03	<0.01	0.002
AISI 304	0.037	0.42	1.54	0.027	0.002	8.47	18.1	0.13	0.056
AISI 316L	0.024	0.39	0.94	0.032	0.002	10.1	17.1	2.01	0.06

* N 0.002 %

Electrochemical measurements



Anoxic environment at room temperature

Open Circuit Potential measurements

Tafel curves for carbon steel

- - 250 mV vs. OCP to +250 mV vs. OCP
- 10 mV/min

Cyclic polarisation curves for stainless steels

- From OCP to 5 mA/cm^2, or to + 1000 mV vs. Ag-AgCl
- 18 mV/min

Corrosion rates calculated using Faraday's law

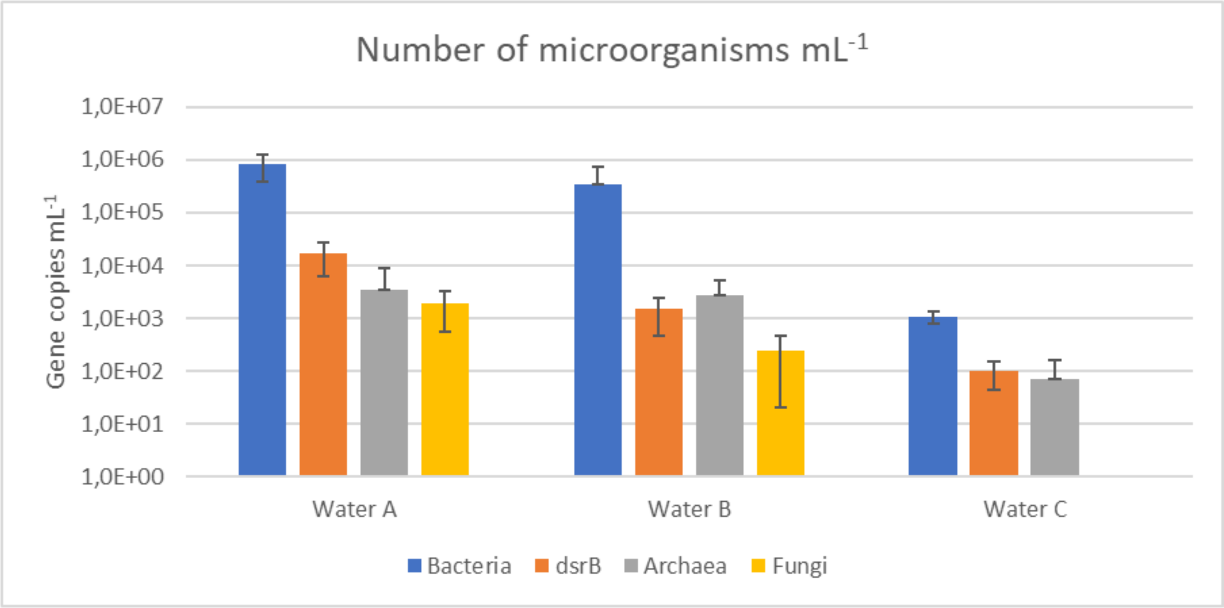
RESULTS: Water composition and microbiology

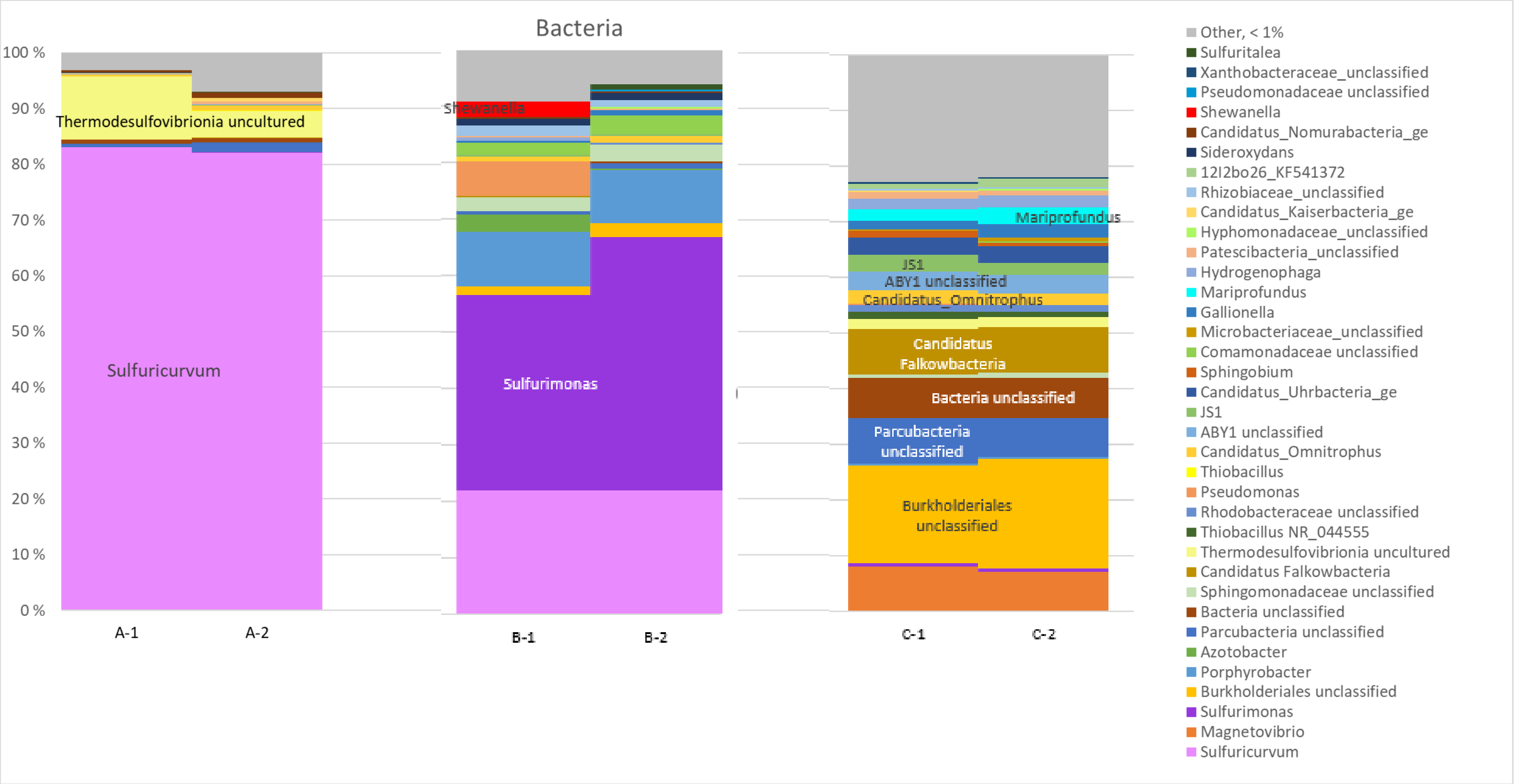
Chemical composition of the waters

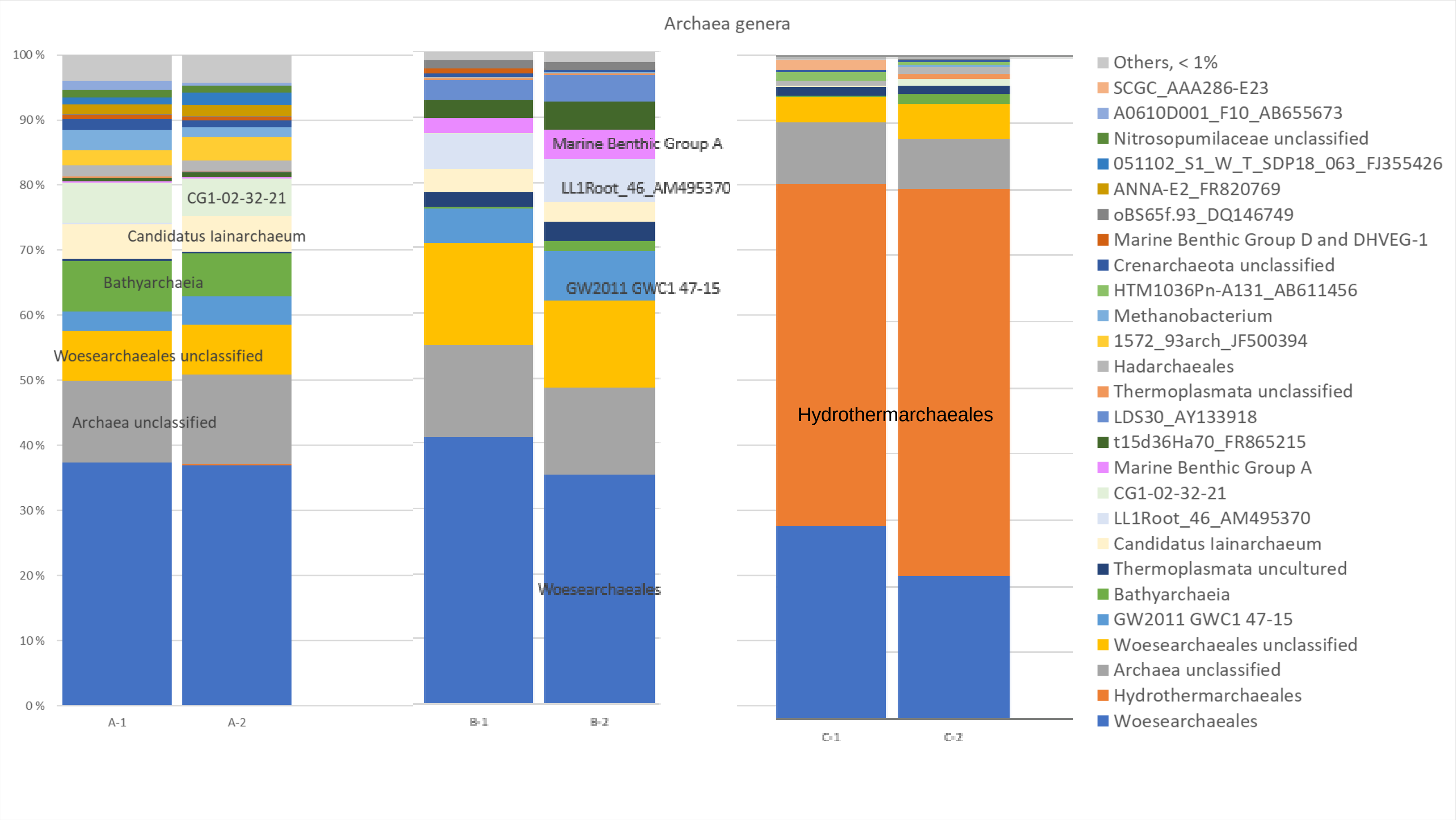
Element/ characteristic	Unit	Water A	Water B	Water C	Simulated water
pH		8.73	7.33	7.74	7
Alkalinity pH 4.5	mmol/L	3.15	5.41	1.82	
CO_2 (total)	mg/L	138	268	87	
HCO_3^-	mg/L	192	330	111	
Phosphate	mg/L	<0.040	0.068	<0.040	
Sulphate	mg/L	116	482	566	500
Sulphide	mg/L	0.147	<0.050	<0.010	
Chloride	mg/L	723	3210	4880	5500
Ammonium	mg/L	0.179	2.9	1.82	
Ca (soluble)	mg/L	56.8	444	615	
Mg (soluble)	mg/L	30.2	109	276	
Na (soluble)	mg/L	489	1380	2210	
S	mg/L	44.4	140	204	
Si	mg/L	2.28	7.23	4.56	
TOC	mg/L	6.37	10.3	1.33	
Sulphate/chloride ratio		0.16	0.15	0.12	0.09

	Water A	Water B	Water C
Pitting index	7.25	18.60	82.14

Number of microorganisms in the waters

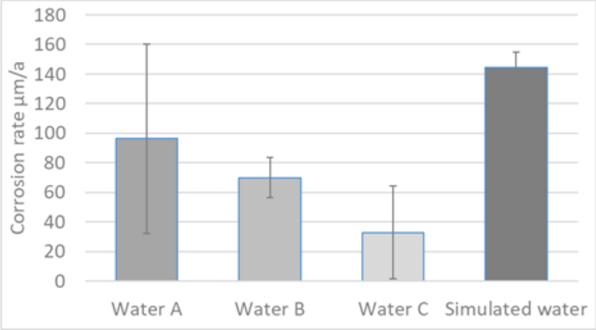



Bacteria
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
Thermodesulfovibrionia uncultured
Sulfuricurvum
Shewanella
Sulfurimonas
Mariprofundus
JS1
ABY1 unclassified
Candidatus_Omnitrophus
Candidatus Falkowbacteria
Bacteria unclassified
Parcubacteria unclassified
Burkholderiales unclassified
A-1
A-2
B-1
B-2
C-1
C-2
Other, < 1%
Sulfuritalea
Xanthobacteraceae_unclassified
Pseudomonadaceae unclassified
Shewanella
Candidatus_Nomurabacteria_ge
Sideroxydans
12I2bo26_KF541372
Rhizobiaceae_unclassified
Candidatus_Kaiserbacteria_ge
Hyphomonadaceae_unclassified
Patescibacteria_unclassified
Hydrogenophaga
Mariprofundus
Gallionella
Microbacteriaceae_unclassified
Comamonadaceae unclassified
Sphingobium
Candidatus_Uhrbacteria_ge
JS1
ABY1 unclassified
Candidatus_Omnitrophus
Thiobacillus
Pseudomonas
Rhodobacteraceae unclassified
Thiobacillus NR_044555
Thermodesulfovibrionia uncultured
Candidatus Falkowbacteria
Sphingomonadaceae unclassified
Bacteria unclassified
Parcubacteria unclassified
Azotobacter
Porphyrobacter
Burkholderiales unclassified
Sulfurimonas
Magnetovibrio
Sulfuricurvum

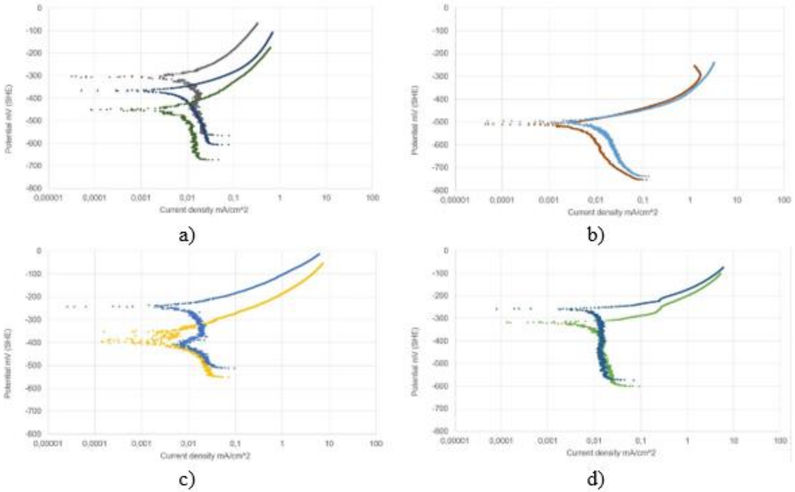

Archaea genera
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
CG1-02-32-21
Candidatus Iainarchaeum
Bathyarchaeia
Woesearchaeales unclassified
Archaea unclassified
Marine Benthic Group A
LL1Root_46_AM495370
GW2011 GWC1 47-15
Woesearchaeales
Hydrothermarchaeales
A-1
A-2
B-1
B-2
C-1
C-2
Others, < 1%
SCGC_AAA286-E23
A0610D001_F10_AB655673
Nitrosopumilaceae unclassified
051102_S1_W_T_SDP18_063_FJ355426
ANNA-E2_FR820769
oBS65f.93_DQ146749
Marine Benthic Group D and DHVEG-1
Crenarchaeota unclassified
HTM1036Pn-A131_AB611456
Methanobacterium
1572_93arch_JF500394
Hadarchaeales
Thermoplasmata unclassified
LDS30_AY133918
t15d36Ha70_FR865215
Marine Benthic Group A
CG1-02-32-21
LL1Root_46_AM495370
Candidatus Iainarchaeum
Thermoplasmata uncultured
Bathyarchaeia
GW2011 GWC1 47-15
Woesearchaeales unclassified
Archaea unclassified
Hydrothermarchaeales
Woesearchaeales

RESULTS:
Steel corrosion

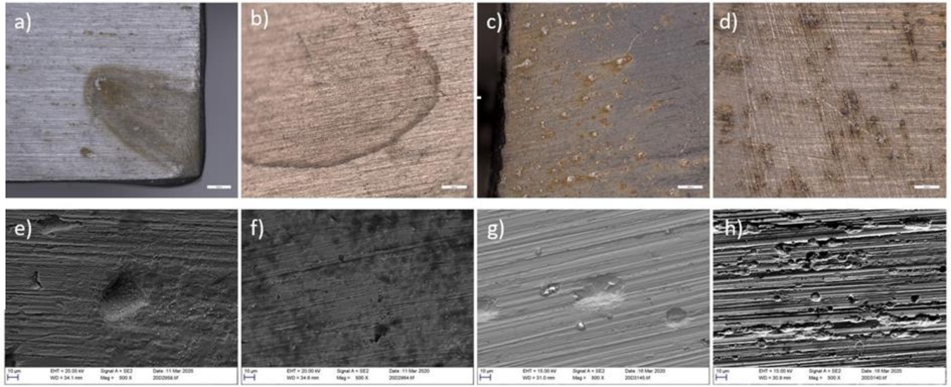
Carbon steel



The average corrosion rates

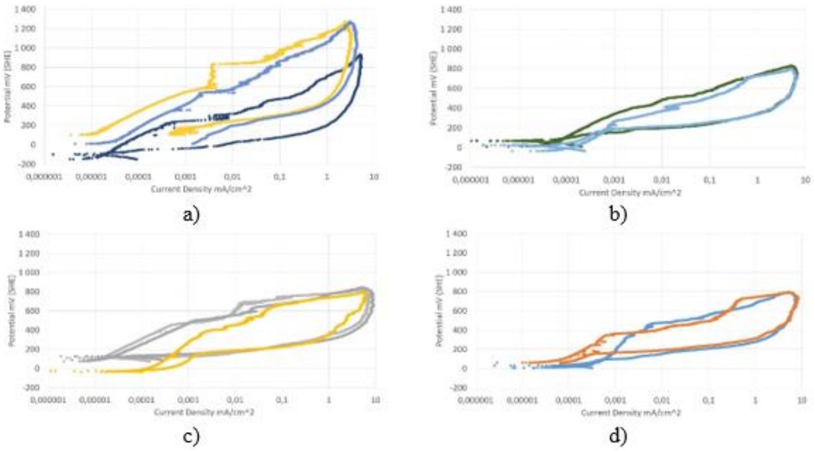


a) water A, b) water B, c) water C and
d) simulated water.

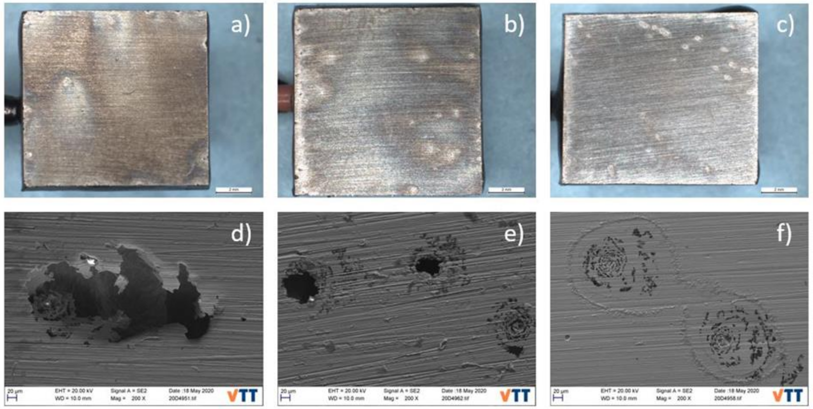


Water A Water B Water C simulated water

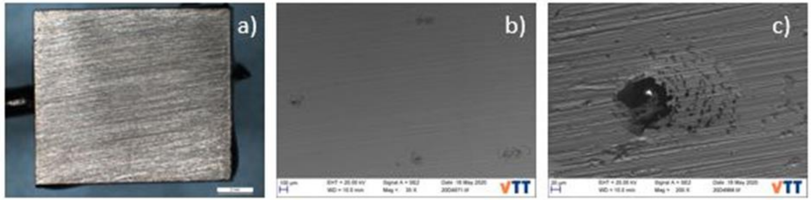
Stainless steel AISI 304



a) water A, b) water B, c) water C and d) simulated water

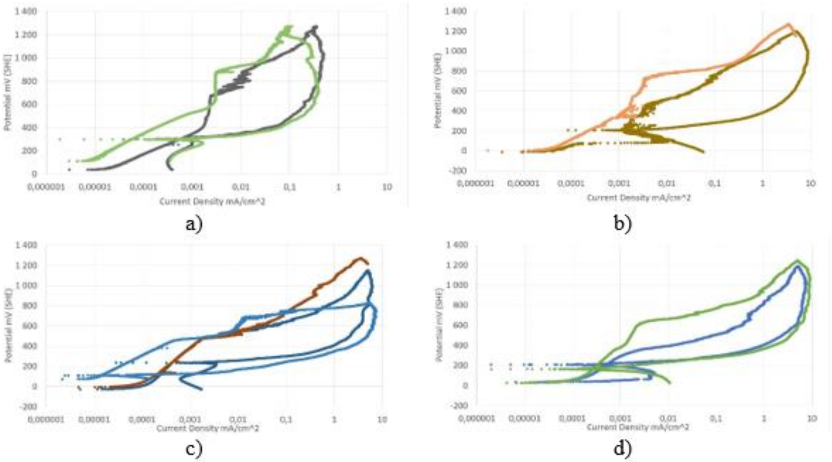


Water A Water B Water C

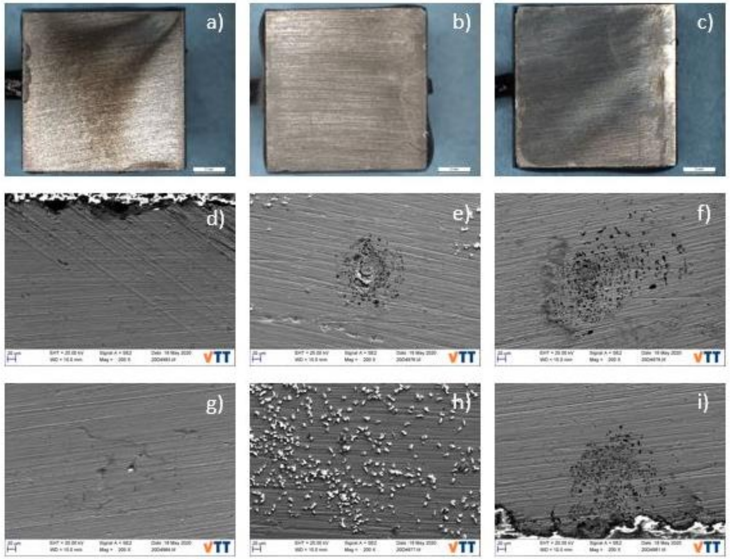


Simulated water

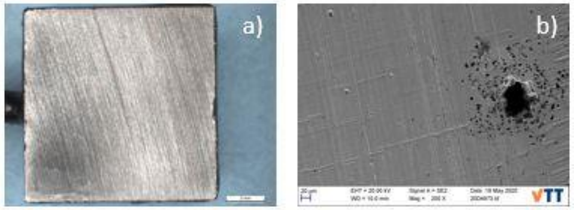
Stainless steel AISI 316L



a) water A, b) water B, c) water C and
d) simulated water



Water A Water B Water C



Simulated water

Conclusions

Conclusions

- the groundwater differed remarkably in their chemical composition as well as abundance and diversity of microbial community
- corrosivity of the natural water and thus the steels' performance in the water can vary a lot depending on the origin of the water
- besides stainless steel also carbon steel suffered from pitting and other localised corrosion, as predicted by pitting index
- the local groundwater conditions have to be taken into account when predicting the durability and expected life repositioning LLW and ILW steel canisters to guarantee the long-term safety of disposal of nuclear waste

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