MOBILITY MISSION REPORT

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MISSION TITLE

Nuclear Corrosion Summer School – NuCoSS-23

DESCRIPTION

Concerned organisations

- Research entities
- Technical support organisations
- Waste management organisations

Concerned infrastructures or facilities

- Underground research laboratory
- Waste packages control facilities
- Nuclear power plants (LWRs, Generation IV reactor)

Concerned phases

- Phase 3: Facility construction
- Phase 4: Facility operation and closure

- Phase 5: Post-closure

Themes and topics

- Theme 3: Engineered barrier system (EBS) properties, function and long-term performance
  - Spent Fuel and high-level waste disposal canisters
  - Containers for long-lived intermediate and low level wastes
  - Clay-based backfills, plugs and seals
  - Cementitious-based backfills, plugs and seals
  - Salt backfills
  - EBS system understanding

Keywords

Nuclear reactors; corrosion; waste package; corrosion characterization; deep geological disposal

EXECUTIVE SUMMARY

Corrosion of steel materials, i.e., the interaction between these materials and their environments, is a major issue for nuclear power plants and deep geological disposal safety as well as for operation and economic competitiveness. Understanding these corrosion mechanisms, the systems, and materials they affect, and the methods to accurately measure their incidence is of critical importance to the nuclear industry.

Combining assessment techniques and analytical models into this understanding allows operators to predict the service life of corrosion-affected nuclear plants and in the future predict long-term safety in deep geological disposal. It is important to apply the most appropriate maintenance and mitigation options to ensure safe and economic long-term operation and waste storage.

The functional lifetime of disposal canisters for spent nuclear fuel will be most important for the long-term safety of deep geological repositories. Its research and development must assure all the aspects including the prediction of its corrosion behavior under repository conditions.

The summer school covered all necessary topics, starting with fundamental electrochemistry and fundamentals of corrosion, to provide a self-consistent understanding of nuclear corrosion by lecturer F. Scenini. Next internationally renowned experts (e.g., D. Engelberg, R. Kilian, H.P. Seifert, P. Efsing, J. Noël, S. Ritter, L. Martinelli, J. Macák) continued giving lectures on the following topics: Electrochemistry and corrosion (incl. hands-on experiments), Overview on corrosion in the nuclear cycle, Corrosion in light water reactor plants (incl. monitoring & mitigation aspects and a focus on environmentally assisted cracking), Corrosion in nuclear waste disposals, Corrosion in Gen IV systems, Case studies and aging management, Advanced technologies to characterize corrosion.

On Wednesday (5.7.) and on Friday (7.7.) there were practical exercises in small groups. We made our own reference electrode and performed simple electrochemical measurements with steel samples. We also learned how to use the software EcmWin.

1. MISSION BACKGROUND

1.1. R&D background

Corrosion of nuclear materials, i.e. the interaction between these materials and their environments, is a major issue for plant safety as well as for operation and economic competitiveness. Understanding these corrosion mechanisms, the systems and materials they affect, and the methods to accurately measure their incidence is of critical importance to the nuclear industry. Combining assessment techniques and analytical models into this understanding allows operators to predict the service life of a corrosion-affected nuclear plant and storage canister materials, and to apply the most appropriate maintenance and mitigation options to ensure safe and economic long-term operation and waste storage.

1.2. Mission objectives

The summer school covered all necessary topics, starting with fundamental electrochemistry, to provide a self-consistent understanding of nuclear corrosion issues. Internationally renowned experts (e.g., F. Scenini, D. Engelberg, R. Kilian, H.P. Seifert, P. Efsing, J. Noël, S. Ritter, L. Martinelli, J. Macák) gave lectures on the following topics:

- Electrochemistry and corrosion (incl. hands-on experiments)
- Overview of corrosion in the nuclear cycle
- Corrosion in light water reactor plants (incl. monitoring & mitigation aspects and a focus on environmentally-assisted cracking)
- Corrosion in nuclear waste disposals
- Corrosion in Gen IV systems
- Case studies and aging management
- Advanced technologies to characterize corrosion

1.3. Mission request

The experience gained at the summer school will be used in assigning and solving projects, as well as getting to know experts in the field, as well as gaining information regarding global corrosion research and materials for storing spent nuclear fuel and high-level nuclear waste.

1.4. Mission composition

Host organisation

NuCoSS-23 summer school is jointly organized by PSI, CEA, Univ. of Manchester and Slovenian National Building And Civil Engineering Institute ZAG (local organizer) and EFC-WP4 (Nuclear corrosion).

Host facility

Not applicable.

Mission dates

2 July 2023 – 7 July 2023

2. MAJOR PRACTICES, TECHNIQUES, METHODS, TOOLS OR SYSTEMS OPERATED OR STUDIED

2.1. Practice, technique, method, tool or system operated or studied during the mission

Electrochemical/corrosion tests

Description

Not applicable for implementation in the host organization.

Usage

During our practical exercises, firstly we prepared our own reference electrodes and later we performed simple electrochemical measurements with steel samples. Three metal samples were measured: iron, nickel, and aluminum. The electrochemical changes were measured in distilled water. We also learned how to use the software EcmWin. We evaluated the corrosion rates of our sample.

Benefits

As a coordinator of research and development of metal canisters for spent nuclear fuel, I must evaluate the output from the experiment in the laboratory from research institutes. The most common techniques used to validate the corrosion rate of the materials such as measuring electrochemical potential are commonly used, because of their fast and easy usage.

Limitations

Electrochemical methods can evaluate the corrosion rate, however, this practice is useful only for short-term experiments. Furthermore, the electrochemical methods for the evaluation of corrosion cannot provide information about the formation of corrosion products. This is important for predicting the interaction of leaching radionuclides from SNF to the atmosphere in the near field.

Applicability

The knowledge will be used in the evaluation of outputs from the research institutes. Understanding common laboratory practices is beneficial and useful in coordinating experiments concerning the metal canister of spent nuclear fuel.

2.2. Practice, technique, method, tool or system operated or studied during the mission

Not applicable.

Description

Not applicable.

Usage

Not applicable.

Benefits

Not applicable.

Limitations

Not applicable.

Applicability

Not applicable.

2.3. Practice, technique, method, tool or system operated or studied during the mission

Not applicable.

Description

Not applicable.

Usage

Not applicable.

Benefits

Not applicable.

Limitations

Not applicable.

Applicability

Not applicable.

2.4. Practice, technique, method, tool or system operated or studied during the mission

Not applicable.

Description

Not applicable.

Usage

Not applicable.

Benefits

Not applicable.

Limitations

Not applicable.

Applicability

Not applicable.

3. MISSION FINDINGS AND CONCLUSIONS

3.1. Lessons learned and conclusions

The introductory lectures covered corrosion and electrochemistry, explaining concepts such as electrochemical potential, Faraday's law, passivation, polarization curve, intergranular corrosion, and heat-affected zone. The effects of various parameters on increasing electrochemical potential and corrosion were discussed. The nuclear accident in Fukushima was analyzed from a corrosion perspective. We explored solutions like hydrogen recombustion and applying coatings on Zircaloy.

Different technologies for corrosion characterization, including electrochemical potential, LIBS, advanced microscopies, ICP-MS Q(QQ), and gas detection, are used for steel. Key areas for assessing corrosion in nuclear power plants are fuel cladding, steam generators, and pressure vessels. Water radiolysis processes create oxidative and reductive species that impact corrosion in NPPs, while neutron radiation causes steel strain localization and radiation-induced segregation.

The challenge lies in predicting and identifying undetectable stress corrosion cracking (SCC) and environmentally assisted cracking (EAC). SCC can be intergranular or transgranular, with long, invisible cracks and minimal corrosion products. EAC occurs in anodic, acidic environments. Microbial corrosion (MIC) is a concern for nuclear facilities and canisters storing spent nuclear fuel (SNF). Strategies to slow down MIC include using resistive matrices, coatings, cathodic protection, regular flow, smooth surfaces, biocides, early damage measurement, and severely damaged system measurement. Stress reduction in steel can be achieved through activities like reducing tensile stress and cavitation.

From a research perspective, SÚRAO should aim to predict SCC and EAC during early canister production stages and explore improved materials and layered canisters. Prevention strategies for MIC on SNF canisters are also a priority. Additionally, Zircaloy corrosion should be considered when predicting fuel assembly manipulation.

3.2. Relevant findings and conclusions for home organisation

3.3. Relevant findings and conclusions for host organisation

3.4. Relevant findings and conclusions for other organisations

4. POTENTIALS FOR IMPROVEMENT OR DEVELOPMENT

4.1. Generic potentials

4.2. Potentials for home organisation

4.3. Potentials for host organisation

APPENDICES

Mission journal

2.7.

17:00-21:00 Lectures about Electrochemistry and corrosion (Introduction to corrosion I and II).

3.7

9:00-12:30 Lectures about Electrochemistry and corrosion (Introduction to corrosion III).

17:30-20:00 Lectures about General Overview on nuclear.

20:00-21:30 Lectures about Corosion in LWRs. Test at the end of the day.

4.7.

9:00-12:30, 17:30 – 21:30 Lectures about Corosion in LWRs. Test at the end of the day.

5.7.

9:00-12:30, 17:30 – 21:30 Lectures about Corosion in LWRs

21:30-22:15 Practical work (building our own reference electrode)

6.7.

9:00-12:30 Lectures about Corrosion in nuclear waste disposal

17:30 – 21:30 Corrosion in Gen IV systems. Test at the end of the day.

7-7.

9:00-12:30 Practical work (electrochemical and corrosion experiments). Practise of using the software.

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MISSION BENEFICIARY

Michaela Matulová
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PARTNER EXPERTS CONTRIBUTING TO THE MISSION

Host organisation experts

- Bojan Zajec, Researcher, Laboratory for Metals, Corrosion and Anticorrosion protection, Slovenian National Building And Civil Engineering Institute (ZAG)

Home organisation experts

- Markéta Dohnálková, Head of the RAW Repository Planning Department, Radioactive Waste Repository Authority (SÚRAO), Czech Republic
- Lucie Hausmannová, Research and Development Coordinator, Radioactive Waste Repository Authority (SÚRAO), Czech Republic

Other organisations experts

- F. Scenini, Lecturer, Materials Performance Centre, University of Manchester
- D. Engelberg, Professor, Materials Performance Centre, University of Manchester
- D. Ferrón, Research Director, Centre d'Etudes de Saclay, Atomic Energy and Alternative Energies Commission
- R. Kilian, Expert, Framatome
- H.P. Seifert, Lecturer, Laboratory for Nuclear Materials, Paul Scherrer Institute
- P. Efsing, Associated Professor, Department of engineering Mechanics, KTH
- J. Noël, Lecturer, Department of Chemistry, Western University of Ontario
- S. Ritter, Lecturer, Laboratory for Nuclear Materials, Paul Scherrer Institute
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- J. Macák, Professor, Power Engineering Department, University of Chemistry and Technology (UCT)

REPORT APPROVAL

Date	Beneficiary	Home mentor/supervisor	Host mentor/supervisor
27.7.23	Michaela Matulová	Markéta Dohnálková	Bojan Zajec

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