

Melanie Polanco, Junliang Liu, PhD

FAMU-FSU College of Engineering, Department of Materials Science & Engineering

## Abstract

In nuclear fusion reactors, corrosion of structural materials by the liquid-metal coolant, a Pb-Li eutectic alloy, can occur under strong magnetic fields due to its high electrical conductivity [1]. In this project, a conductive fluid loop was designed and customized to simulate corrosion under strong magnetic-field conditions. This loop enables preliminary corrosion testing of materials under varying flow rates and magnetic field strengths, using seawater as the conductive fluid. Due to its conductivity and ease of handling compared to liquid metals, seawater is an ideal candidate for this experiment, making this study scalable to harsher conductive fluids. The effect of magnetic fields on corrosion is being evaluated by comparing tests performed in the field with those conducted without the applied field.

## Background

- Nuclear fusion is a promising clean energy source because it has the potential to provide large amounts of low-carbon energy using abundant fuel resources.
- One of the most important features of a fusion reactor is the use of strong magnetic fields to confine plasma at temperatures exceeding 100 million K [2].
- These exceedingly high temperatures create an extreme environment for structural materials. Materials must be tested under extreme conditions to determine their viability for prospective fusion reactors.

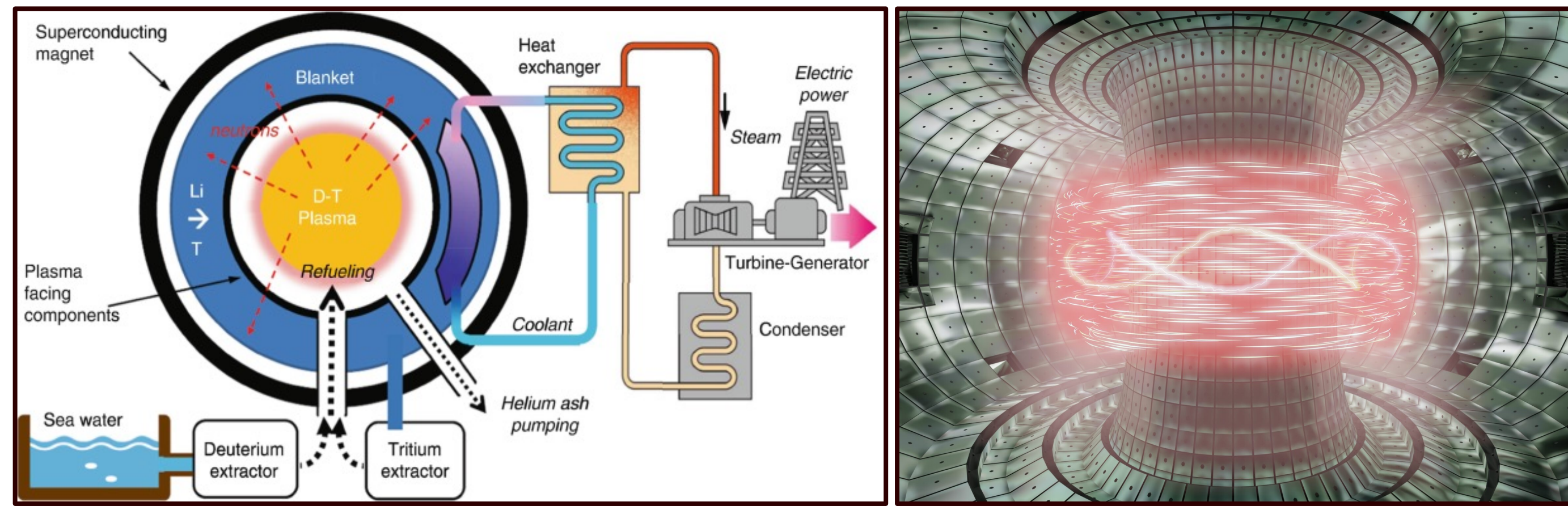


Figure 1. Schematic of a magnetic confinement fusion reactor [3].

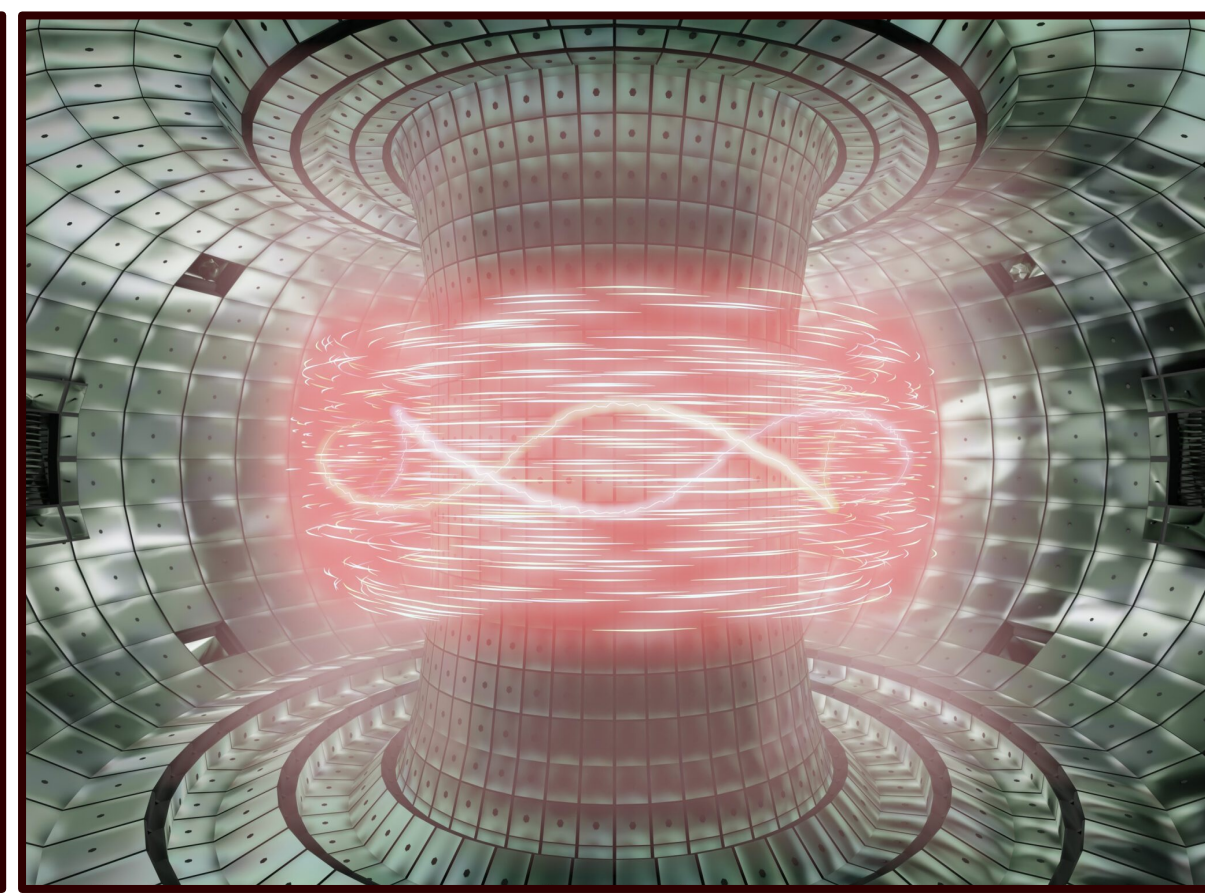


Figure 2. Representation of a tokamak nuclear fusion reactor plasma confinement system [4].

- Corrosion is a degradation process driven by electrochemical charge transfer, which leads to the deterioration of materials over time [5].
- Corrosion of structural materials in a fusion reactor may occur under the influence of strong magnetic fields used for confinement.
- When an external magnetic field is present, induced voltage and current directly influence the electrochemical processes involved and therefore affect local corrosion behavior [6].

## Corrosion of Materials in Seawater: In-Field Experiment

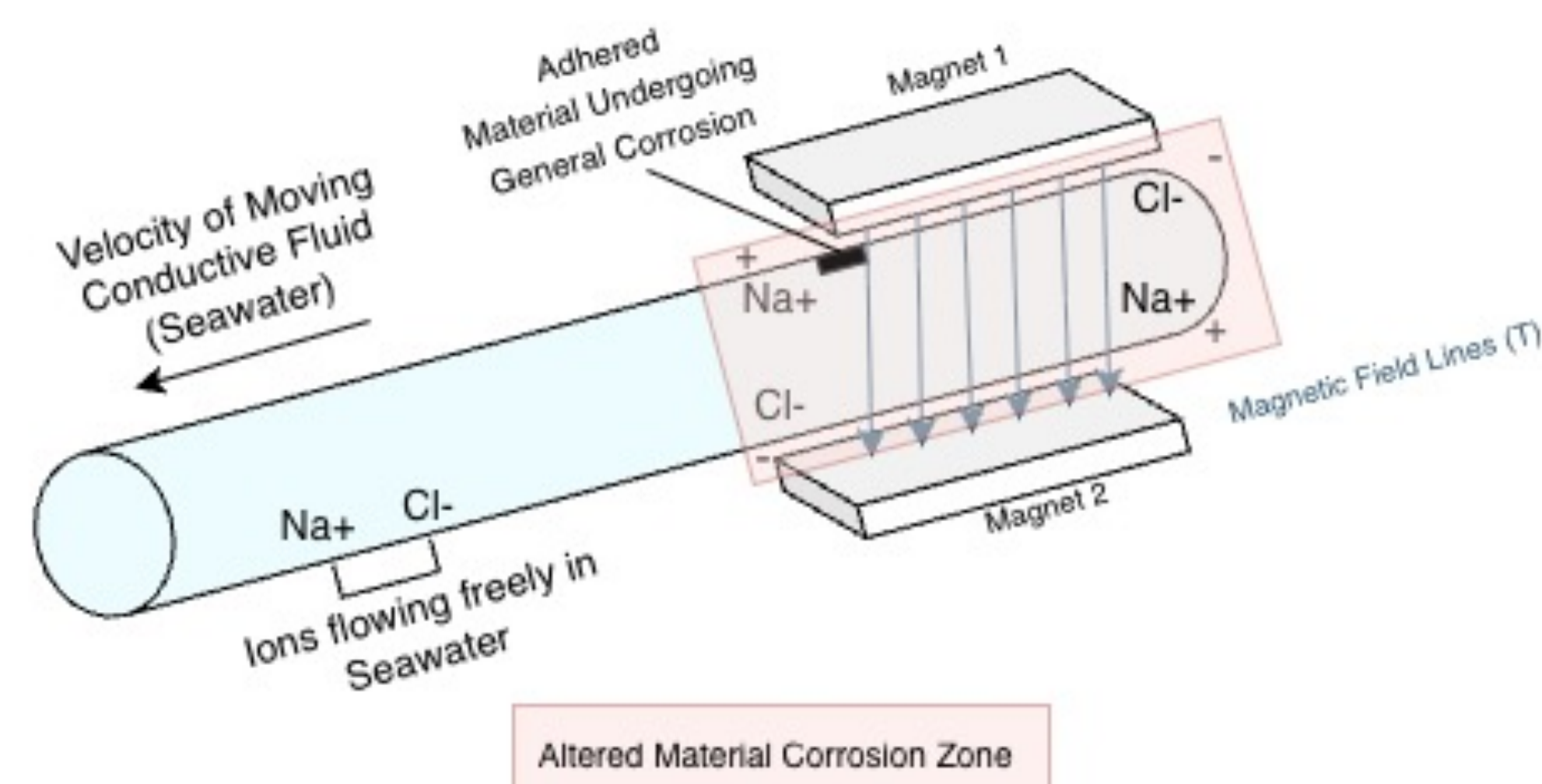
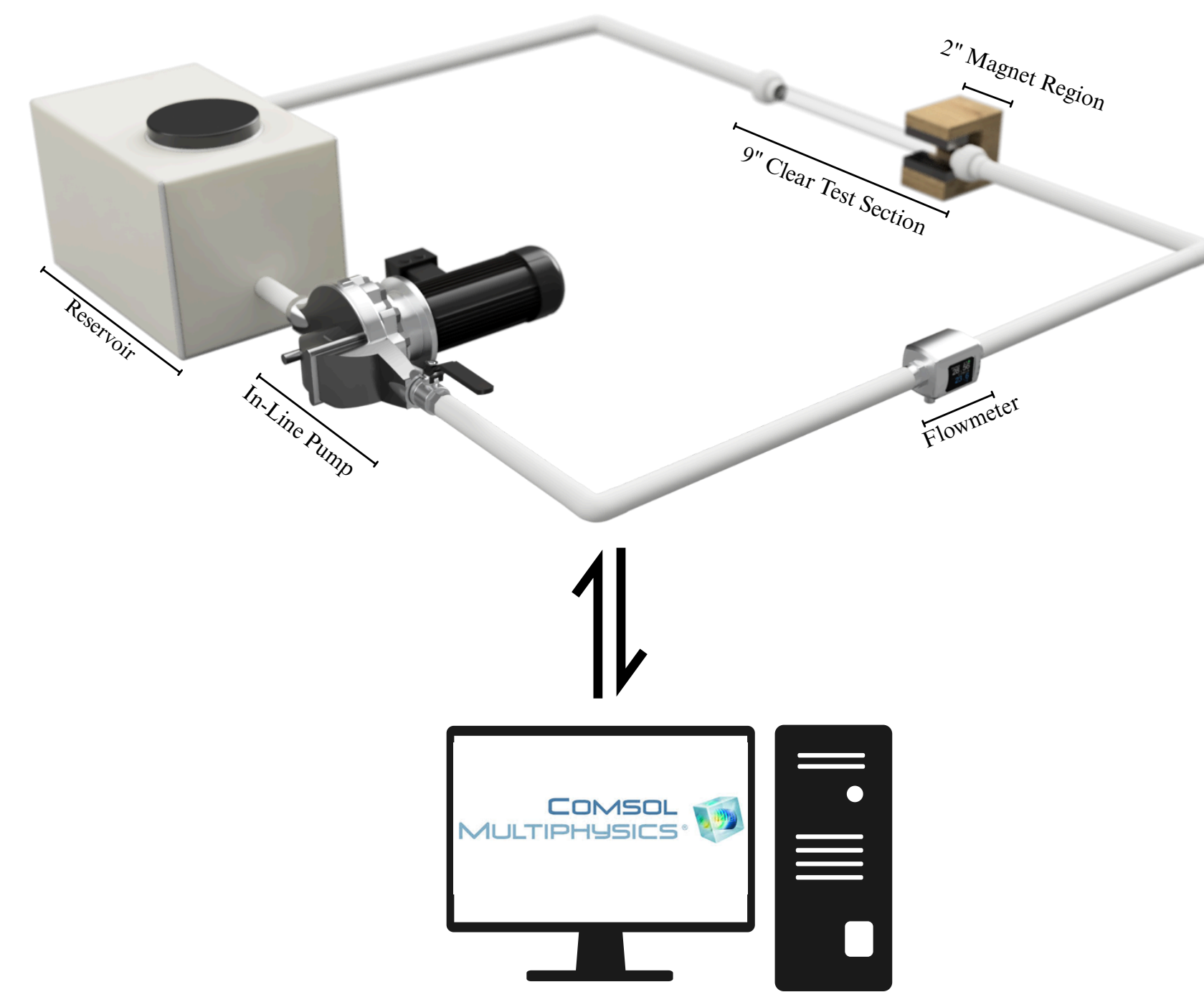


Figure 5. Diagram displaying an experimental corrosion setup of a material adhered to the test section interface exposed to flowing seawater and an applied magnetic field.

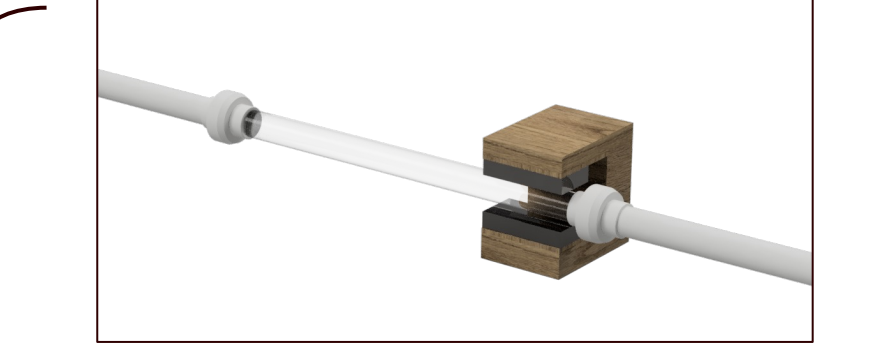
## Experimental Setup

### In-Field Corrosion Loop



### Test Section COMSOL Data Collection

### 1. In-Field Testing



### 2. No Field Testing

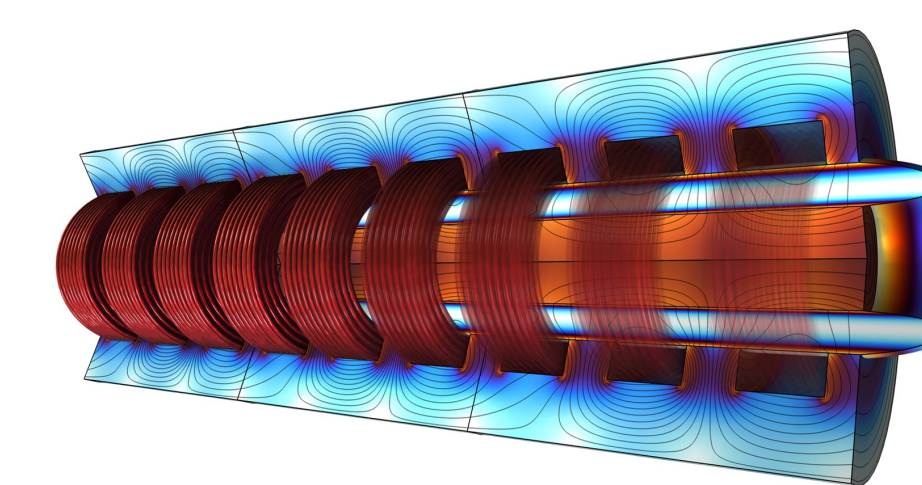


Figure 6. COMSOL Multiphysics simulation visualization of a lithium pump using the magnetohydrodynamics interface [7].

## Hypothesis, Experimental and Simulation Conditions

- Seawater flows through the 9" pipe representing the experimental test section, acting as a conductive electrolyte containing mobile ions.
- An external magnetic field of 0.1 Tesla (T) is applied 2" across the beginning of the test section.
- The fluid domain models the moving conductive seawater, where magnetohydrodynamic interactions occur.
- The air domain surrounds the system, allowing magnetic field lines to form naturally
- Seawater conductivity ( $\sigma = 4.5 \text{ S/m}$ ) enables the generation of an electric current when ions move through a magnetic field [8].
- The interaction between fluid motion and magnetic field induces electric potential and current density, influencing corrosion behavior in exposed materials

## COMSOL Multiphysics Boundaries and Domains

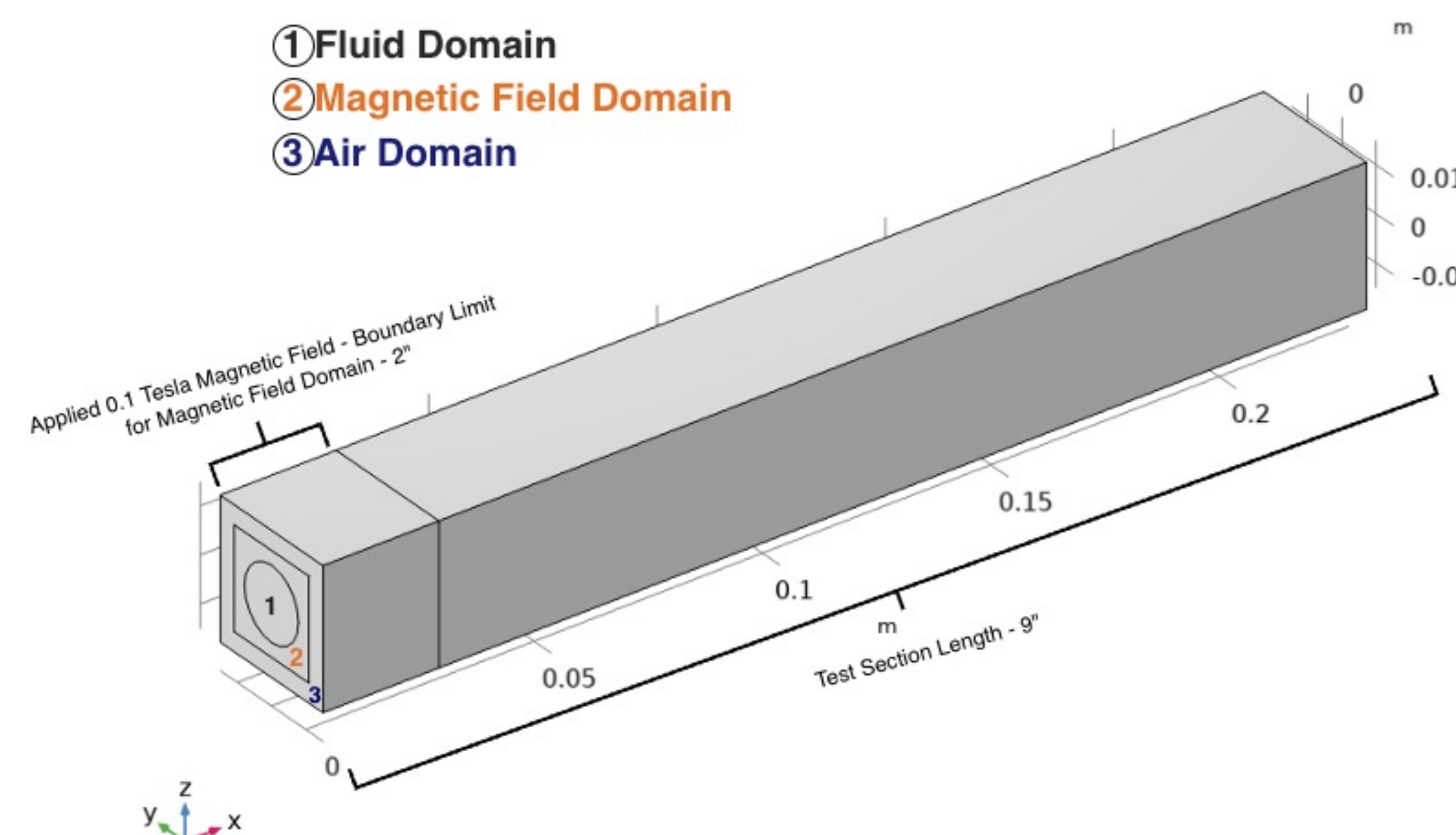


Figure 7. Annotated display of COMSOL Multiphysics geometry with labeled domains for the corrosion experiment in-field.

## Results and Discussion

### Electric Potential (V)

- Inside the magnetic field, moving seawater ions are pushed in opposite directions, which creates an electric potential across the flow.
- After the magnet region, the magnetic field suddenly disappears, so the charges rearrange, causing the potential to flip.
- The boundary pattern forms because the currents must curve and redistribute before they fade downstream.

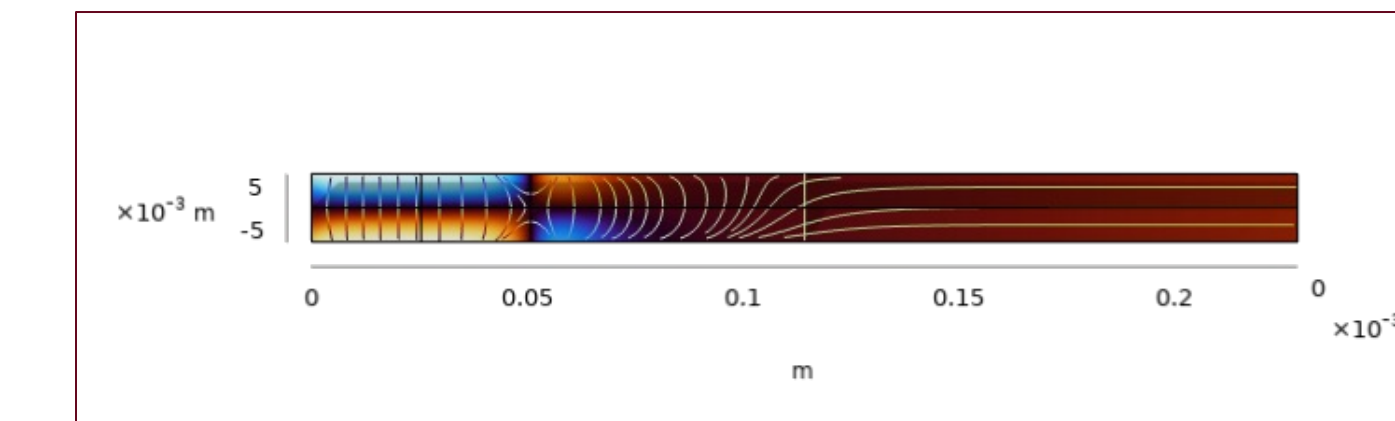


Figure 8. COMSOL Multiphysics Simulation visualizations for electric potential distribution displaying a 'corkscrew' pattern.

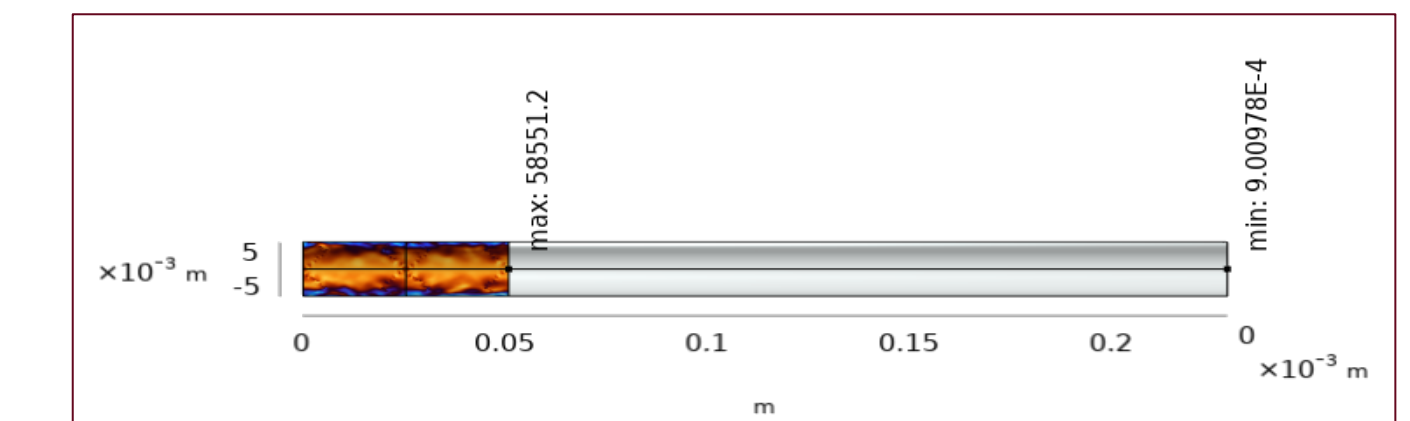


Figure 9. COMSOL Multiphysics visualizations for surface current density displaying a maximum at the magnetic field boundary and a minimum at the end of the test section.

### Current Density (A/m)

- Inside the magnetic field, the moving seawater generates strong electrical currents, which is why the current density is concentrated in the magnet region and peaks near the boundary where the field ends due to the sudden shift from equilibrium.
- Higher current density can increase electrochemical reactions at the material surface, meaning areas with stronger induced currents may experience more localized corrosion effects than regions where the current quickly fades across the rest of the test section.

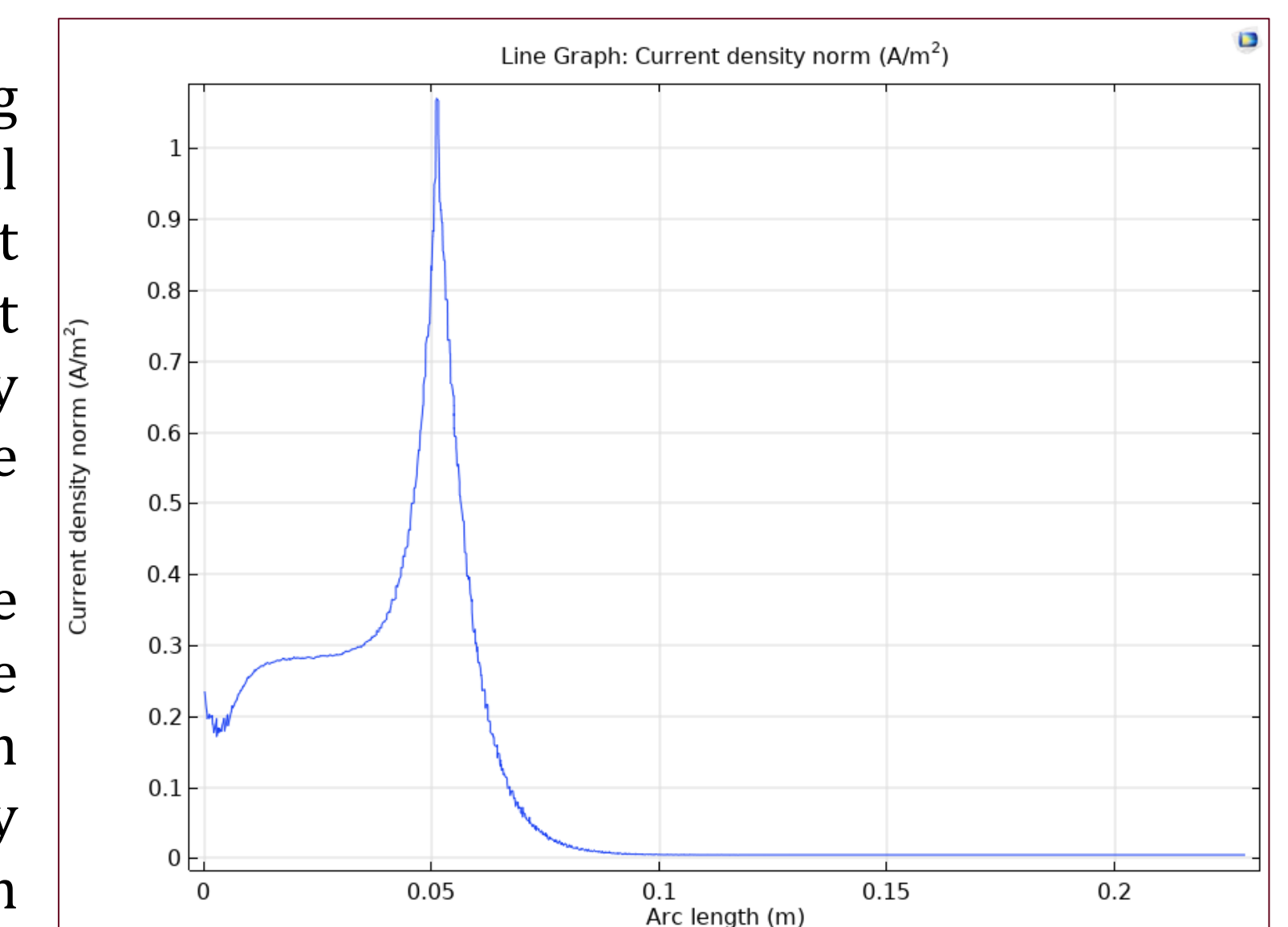


Figure 10. COMSOL Multiphysics Simulation graphical data showing a non-zero induced current density in the test section and a maximum peak at the magnetic field boundary.

## Conclusion

- Conductive liquids flowing through a magnetic field generate measurable electric potentials and current densities due to magnetohydrodynamic (MHD) interactions.
- Charge behavior differs significantly with and without an applied magnetic field.
- Electrical effects are concentrated within the magnetic field region, especially at its boundaries.
- Because corrosion is driven by electrochemical charge transfer, localized increases in current density may influence corrosion behavior.
- These results indicate magnetic fields may alter corrosion conditions in environments such as fusion reactor cooling systems.

## Acknowledgements

Firstly, I would like to thank Dr. Liu for his unyielding mentorship and guidance throughout this project. Special thanks to Mushfique Mahmood and Naufel Solaiman for their support. Most importantly, I would like to thank Florida State University's Undergraduate Research Opportunity Program (UROP) for laying the foundation for the pursuit of this investigation.

## References



## LinkedIn

