PREDICTING CORROSION MORPHOLOGY IN BCC SINGLE CRYSTALS IN NUCLEAR MOLTEN SALTS

NUCLEAR ENERGY: OPPORTUNITY OR ANXIETY?

A Thesis Prospectus
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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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INTRODUCTION

As the impacts of climate change are felt more and more, society pushes for clean energy. When considering alternative energy sources, there are five primary options: hydroelectric, geothermal, solar, wind, and nuclear. Solar and wind power are viewed most positively by the public in a 2021 survey of 2,200 US adults across various geographies and political alignments (Jenkins, 2022). Hydroelectric and geothermal were next, with largely positive or neutral opinions. Nuclear energy was at the bottom of these technologies, having similar approval rates as coal and oil. However, to fully electrify the US on wind and solar alone would take land five times the area of South Dakota, while using nuclear would only require land half the area of New Hampshire (Yglesias, 2022). If the US aims to reach carbon neutrality by 2035 (The White House, 2021), nuclear alternative energy sources must be considered. The advancement of nuclear energy provides both incredible opportunities and anxieties to the public.

Currently, the most common type of nuclear reactor is a Generation II reactor (World Nuclear, 2022), the primary sub-types of which are pressurized water reactors and boiling water reactors. These reactors use water to actively cool the fuel rods as power is generated. However, due to the high operating temperatures, the water must be pressurized so that it does not boil and continuously pumped to transfer heat. During the Fukushima boiling water reactor meltdown of 2011, environmental disasters resulted in both the grid power and the emergency generator to shut down, causing these active cooling systems to fail and the reactor to overheat (Columbia University, 2016). Newer reactors in operation are called Generation III reactors. They are passively safe, meaning that they use spontaneous laws of nature to cool themselves both during operation and in the event of an emergency (“Use of passive safety”, 2017). However, their main drawback is that their efficiency is not as high as it could be. Currently these reactors have efficiencies comparable to coal. Generation IV nuclear reactors are future reactor designs whose optimizations seek to maximize both operational safety and profit. These reactors are designed to operate at higher temperatures which would greatly increase fuel efficiency and energy output. However, they are also designed to have the built-in passive safety features of Generation III reactors to prevent any further meltdowns. My research is for molten salt nuclear reactors (MSRs), a type of Generation IV reactor. These reactors use molten salt as a coolant instead of water, allowing them to operate at significantly lower pressures than traditional reactors. The coolant also allows for passive heat decay, preventing pressure build ups which caused accidents like the explosions at Fukushima (Touran, n.d.). However, there are also many problems associated with MSRs, namely material degradation, maintenance, and leakage. Thus, extensive research is being performed to solve these problems and allow for MSRs to be a viable reactor of the future.

The technical portion of my prospectus will discuss the future of nuclear reactors, while the STS (Science, Technology, & Society) portion of my prospectus will discuss their past and present. My technical research project aims to increase the scientific understanding of corrosion in molten salt reactor conditions, and my STS investigation will examine how public perception of nuclear energy has influenced its adoption in the US.

MOLTEN SALT CORROSION

Although MSRs have many advantages, corrosion issues remain one of the most challenging disadvantages of the technology. Unlike in traditional water-cooled reactors, metal parts in molten salt baths cannot be coated with a corrosion-resistant oxide film as it is thermodynamically unfavorable (Guo, Zhang, Wu, & Zhou, 2018). Thus, the parts are subjected to severe corrosive attack. As early as the 1950's, Oak Ridge National Labs and many other researchers have reported that structural metals used for reactor vessels and heat exchanger tubes corroded catastrophically within months of MSR operation (Jordan, Cromer, & Miller, 1956). This corrosion occurs because the molten salts are not in thermodynamic equilibrium with the solid metals. Thus, spontaneous oxidation occurs, dissolving the metal into solution and causing significant material degradation, see Figure 1. To continue the advancement of MSR technology, metal corrosion in molten salt must be better understood and controlled.

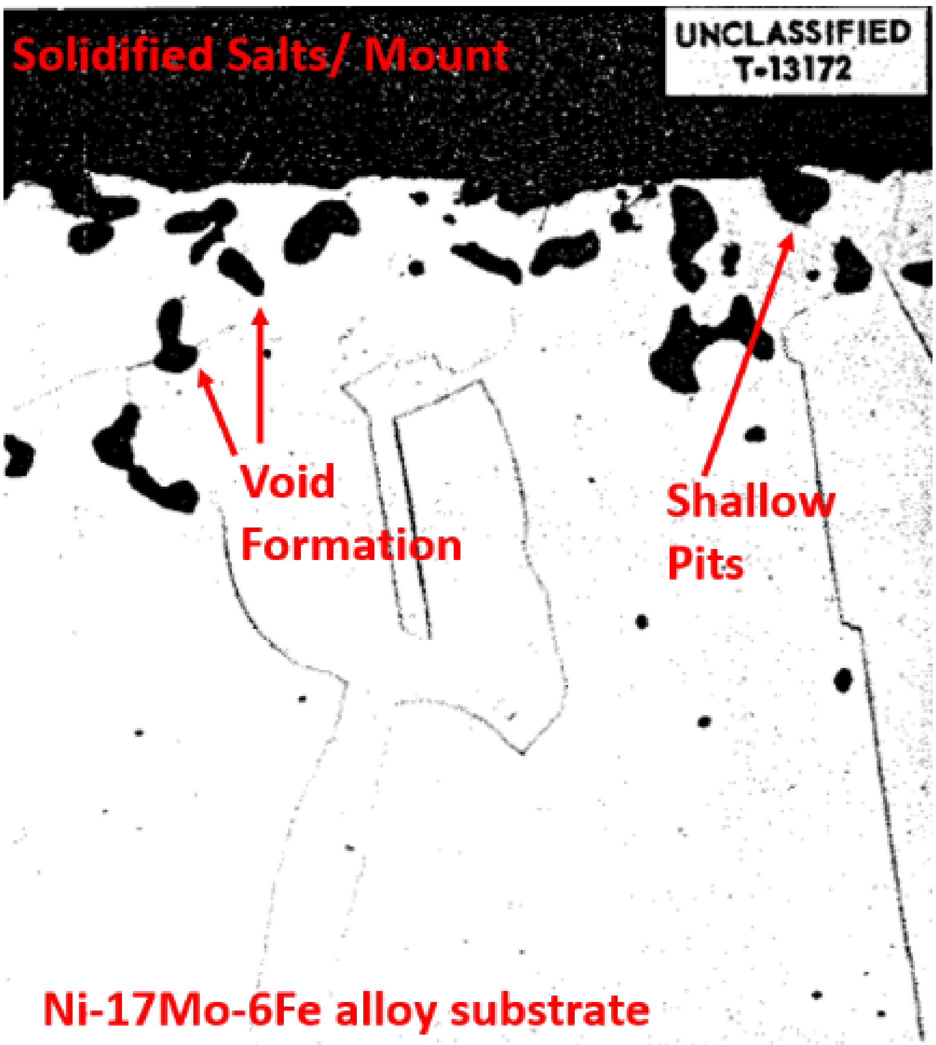

Figure 1. Micrographs of Ni-Mo-Fe alloys tested in FLiNaK molten salt. (Jordan et al. 1956)

The proposed solution is to take known corrosion mitigation strategies of materials in water-based fluids and test them in molten salt environments. That data can be used to optimize a given material's molten salt corrosion resistance for use in a power plant. My research focuses on understanding the electrochemical kinetics of pure nickel and chromium in molten fluoride salts. These metals were chosen because alloys of nickel and chromium display incredible high temperature mechanical properties, making them strong candidates for MSR use (Zahrani, & Alfantazi, 2012). However, very little is known about their electrochemical properties in molten fluoride salts. In the past, studies on molten salt corrosion have used a phenomenological approach, submerging samples in molten salt for a given time and reporting mass loss and surface microstructure once removed (Qiu, Xiang, Dai, Wang, & Zhou, 2021). These studies are very helpful for identifying corrosive attack types but give no information on the time-dependence of such corrosion rates. I will submerge these metals in molten salt along with platinum reference and counter electrodes, measuring the corrosion current density and generating time-dependent corrosion rates and attack type information. The orientation of atoms in a material (crystallographic orientation) has been demonstrated to impact the corrosion rate of a surface in water-based solutions (Dong et al., 2020), so this will also be examined in my work via the same methods. Thus, the two goals of my research are to generate time-dependent corrosion data for pure nickel and pure chromium samples and to determine the most corrosively resistant crystallographic orientations for each material.

If these goals can be successfully accomplished, they will provide foundational data for the use of these materials in MSRs. The orientational corrosion rates will aid the advancement of molten salt reactors since designers would not need to worry as heavily about corrosive failures. Nickel and chromium parts could be processed so that the entire sample has the most corrosion-resistant crystallographic orientation. Since the rate of corrosion for that given orientation would be known, the rate of material degradation could be calculated. Then, an appropriate corrosion damage depth and the resultant lifespan of a given part could be determined (Y. Bai & Q. Bai, 2007). Operators would know how often integral parts of the system would need to be replaced, preventing reactor failure and increasing confidence in the technology as a whole. Relating back to the societal aspect of nuclear reactors, an increased confidence in the safety of nuclear technology is crucial to its increased adoption and use in the future.

NUCLEAR ADOPTION

Nuclear reactors appear in the media most often when something goes terribly wrong. It is unlikely that someone would turn on the news and see a story about a nuclear reactor continuing to run smoothly, it simply wouldn't be news. However, the stories people do see or read about are those like Three Mile Island, Chernobyl, or Fukushima—catastrophic accidents that cause loss of life and infrastructural damage (Cho, 2021). My STS research will be focused on the past and present adoption of nuclear energy in the United States.

One group of interest in the development of these reactors is the civilian public. If the only news someone had heard about nuclear energy was that of a meltdown, they would be against a reactor being built near their community. Public opposition has brought an end to multiple nuclear energy projects such as the Yucca Mountain nuclear waste storage project (Cohen, 2022). This perception then moves us towards another important group: politicians. If nuclear power is disliked by the public, officials may be less likely to support it for fear of not being reelected. They may also worry that a decisive decision on a controversial topic may decrease support for their higher priority programs. However, since reactors are multi-billion dollar infrastructure projects (Department of Energy, 2021), government funding and subsidies are crucial to their increased use. Thus, the non-expert opinion of nuclear power has heavily influenced its continued development.

The framework I will be relying upon for my research is Everett M. Rogers's Attributes of Innovations and their Rate of Adoption (1983). This framework analyzes how an individual or group's perception of a technology changes the speed with which they accept and use it. It breaks an individual or group's perception down into five categories—relative advantage, compatibility, complexity, trialability, and observability—and uses those categories to explain a technology's rate of adoption. In addition to the perception, four slightly more tangible variables were determined to influence adoption rate: type of innovation decision, communication channels, nature of the social system, and extent of change agent's promotion efforts. Although these four other variables may overlap with each other—such as promotion efforts changing communication channels—they provide helpful structure to examine more concrete variables. These categories and external factors influence each other, changing the amount satisfaction required for one if another changes. For example, farmers in Sweden adopted more complex farming technologies if the information communication was interpersonal (Petrini, 1968). If they simply saw mass media ads for the technology, they were significantly less likely to adopt it.

This framework aids my investigation on the adoption of nuclear energy incredibly well. It will allow me to analyze key groups of individuals such as the US government, private energy companies, or communities near a proposed reactor and use their perceptions to explain the outcome of a given event.

RESEARCH QUESTION AND METHODS

The research question I will be asking is: How have social perceptions of nuclear energy influenced its adoption in the US? It has already been shown that nuclear energy must be explored if the US is to successfully transition away from fossil fuels. This transition is not a purely technical one though, requiring both strong governmental and civilian support to occur. Therefore, I hope to explain and contextualize what is holding nuclear energy back from widespread use.

To investigate this research question, I will use a series of case studies of proposed nuclear infrastructure. The goal is to compare instances where the nuclear project was successful against instances where it was shut down and to explain why some succeeded and others failed. Data such as government funding, private funding, public outreach, county wealth, and geographical history with nuclear power will be collected for each case such as the failed Yucca Mountain waste storage project or the operational Plant Vogtle in Georgia ("Vogtle Unit 3, 2022). Another case which will be helpful to investigate is the proposed costal reactor in Mendocino, California (Peelle, 1974), since it was proposed before any of the major nuclear accidents. Thus, the perceptions of safety for this failed proposal are of particular interest. For each case, I will identify the key groups involved and use Rogers's framework to analyze why a given group was or was not keen on adopting nuclear technology. I will also determine the amount of power each group has on the final decision. If a given group is incredibly for or against the project but has very little power, their opinions are less influential for the outcome of a case.

CONCLUSION

Molten salt nuclear reactors have the potential to be safer and more efficient than current reactors. However, material degradation from corrosion still presents a large problem for their future use. My research aims to determine the most corrosion-resistant orientation of nickel and chromium and quantify their corrosion rates so that components will last longer before replacement. If this research succeeds, Generation IV reactors will be safer which would hopefully lead to increased public support for these technologies. However, increased civilian support is not the only driving factor in the advancement of this field. Support from private companies and the US government is also incredibly important for the technology's continued growth. My STS oriented research aims to examine how the perceptions of key actors influence the adoption of nuclear energy across the US, examining the power dynamics, values, and actions of the actors involved. Preliminarily, I expect the research paper results to show that civilian perception has far more influence on government project outcomes because civilian influence often manifests itself in government action.

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