Extraction of thorium from monazite sands

Digital communication and its influence on nuclear energy

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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As humanity develops more advanced technologies, power has become a critical component of daily life. Hydrocarbon fuels such as coal and oil have long since been the primary source of energy production globally, but their use has become a topic of contention (Peter, 2018, p. 1557). Their usage has continued to pollute the environment through the propagation of harmful emission of sulfates and other heavy metals like mercury. These particulates are harmful to human respiratory systems, poison wildlife, and acidify bodies of water (Union of Concerned Scientists, 2017). Efforts to reduce waste emissions from hydrocarbon fuel plants have largely proven ineffective. This has already shown major environmental consequences; carbon dioxide and methane, prominent emissions from coal combustion, are able to trap heat from leaving the atmosphere, leading to global warming. It has also accelerated a rise in the sea level, heat waves, and loss of animal species. The need for an energy source whose environmental effects are less severe is necessary to prevent irreversible damage to the planet (Union of Concerned Scientists, 2017).

Non-hydrocarbon reliant energy sources have begun to be implemented as a way of weaning humanity's reliance off of non-renewable fuels. Wind turbines and solar farms are recent developments that are indicative of this trend. Despite recent breakthroughs and popularization, their energy output is currently unable to match that of non-renewable sources. Currently, non-nuclear non-hydrocarbon energy sources make up 17.5% of the total electricity generation in the United States, while hydrocarbon fuels make up 62.7% (U.S. Energy Information Administration, n.d.). The current rate of global warming is unprecedentedly high, with carbon dioxide levels reaching concentrations above 300 parts per million, a value never before seen for millennia (National Aeronautics and Space Administration, n.d.). The environmental consequences so far are evident, and without intervention will only worsen. My technical research and loosely coupled

STS research aim to help alleviate the energy crisis by evaluating the current status of nuclear energy technology and potential strategies to increase its viability. Technically, my team plans to design a process to produce thorium nuclear fuels that are more efficient and less weaponizable than traditional uranium fuels. The STS research bolsters this innovation by evaluating the reasons behind the negative American public opinion on nuclear energy and the various actors who have influenced and altered this opinion over the years. Both objectives are to be accomplished by the end of Spring 2021. The groundwork for these projects will be established by the end of Winter 2020, with the next few months dedicated to their realization. On the technical side, that will be focused on collaboration with the team to model the physical and economical properties of the various systems within the refinement process, while the STS side will involve the collection of relevant data and sources to reach an informed conclusion about the matter. Both these projects will culminate with relevant reports and conclusions about the feasibility and future of nuclear technology with respect to these topics.

EXTRACTION OF THORIUM FROM MONAZITE SANDS

With the supervision of Chemical Engineering Professor Eric Anderson, Chemical Engineers Anna Winter, Karl Westendorff, Peter Sepulveda, Ben Newhouse, and I will look at the production of thorium fuels from monazite sands. Thorium, which is three times more abundant than uranium, is found primarily within the phosphate mineral monazite, which contains about 6% thorium by mass. It could serve as a viable alternative to uranium in nuclear plants for a variety of reasons; the predominant source of fuel used in commercial power plants is uranium, which must undergo an enrichment process to become fissile (World Nuclear Association, 2017). Once the uranium fuel has been spent, it becomes highly radioactive waste which must be properly disposed of or stored. This radioactive waste requires tens of thousands of years to decay to safe levels, and there are environmental risks associated with continued pileup of uranium waste, especially because the government has been slow to act in processing the waste (Brady, 2019, para. 1). In addition, plutonium is one of the byproducts of uranium fission and can be extracted from the spent fuel and utilized in nuclear weapons, meaning that considerable amounts of effort need to be put towards storage security.

THE ADVANTAGES OF THORIUM FUELS

Thorium-232 is a naturally occurring radioactive isotope and is used for generating energy. It is found at a concentration of about 6 ppm in average soil. Thorium-232 is not a fissile nuclear fuel, meaning its atoms cannot be split to generate energy, but it is a fertile fuel (Lu, Yang, & Zhang, 2012, p. 1). As a result, thorium used in conjunction with a small amount of uranium-233 as a driver will produce viable fuel in a reactor. The thorium is transmuted to fissile uranium-233 when it absorbs neutrons from the driving component (David, Huffer, & Nifenecker, 2007, p. 24). The advantage of thorium fuels lies in the abundance of thorium compared to other nuclear fuels. India has invested in thorium reactor technology heavily since they have the largest known resources of thorium in the world but virtually no uranium. Brazil, Australia, and the U.S. all also have significant thorium resources available to them (World Nuclear Association, 2017). Additionally, thorium reactors are less of a security concern than uranium ones. Thorium itself cannot be used in nuclear weapons and the uranium-233 produced in thorium reactors has historically been ineffective and difficult to use when creating weapons of mass destruction (World Nuclear Association, 2017).

A PROCESS FOR THE MASS PRODUCTION OF THORIUM OXIDE

The technical project aims to design a process to take ground monazite ore and purify it into a product stream of thorium oxide and a byproduct stream containing rare earths and uranium.

The elements enter the process as phosphate compounds in the monazite sand and will first be leached with sulfuric acid (Amaral & Morais, 2010, p. 499). Following this acid digestion, the rare earths and uranium are separated in a pH controlled precipitation vessel using ammonium hydroxide. The thorium hydroxide obtained from precipitation is mixed with nitric acid to form thorium nitrate that can then undergo extraction with tributyl phosphate in kerosene. The last step of the purification involves turning thorium nitrate into thorium oxalate using oxalic acid so that it can then be calcined into thorium oxide (Salehuddin et al., 2019, p. 632). Figure 1 is a rudimentary flow diagram for the process and details all the pertinent equipment and streams within the system. Further separations of the uranium and rare earth metals into their saleable products will be outside the scope of this project. The thorium oxide exiting the process will be at a high enough purity for it to be used as fuel in a reactor.

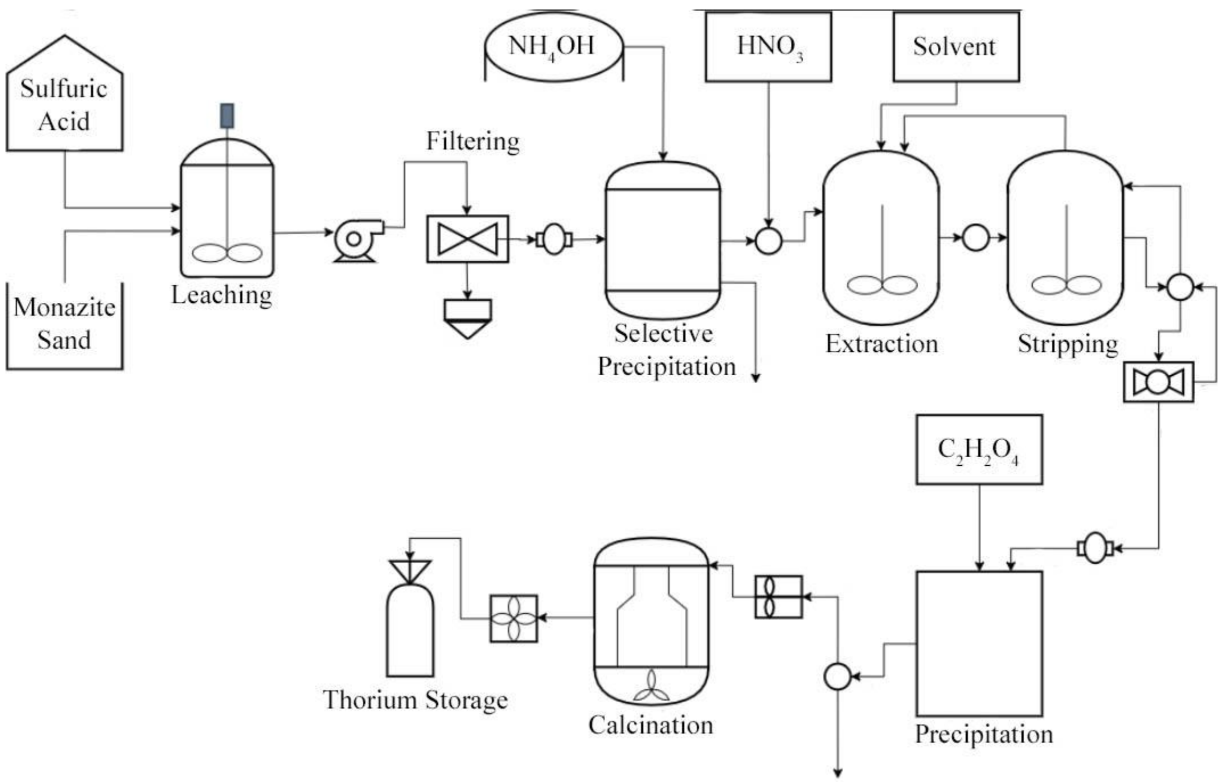

Figure 1: Process Flow Diagram for Monazite Refinement: Monazite sand is fed through a multistage process of leaching, selective precipitation, extraction, stripping, precipitation, and calcination to isolate thorium products (Winter, 2020).

This project will be completed over the course of two semesters as a part of CHE 4438/4476. Aspen Plus will be used to simulate the overall process, and an additional plugin created by OLI Systems will be used for the ionic properties of Th, U, and other heavy metals found in monazite sand. Data for the design process and physical properties will be obtained from Shaw (1953), whose process designed within Iowa State University had a very similar refinement process (p.1 - 2). Modern economic data will be obtained from Salehuddin (2019) and his analysis of viability of a large-scale refinement process to make a profit (p. 634). The overall objective of this project is to produce a functional process diagram of the entire refinement process, and a report on the feasibility of monazite refinement into thorium fuels and its potential scale up.

DIGITAL COMMUNICATION AND ITS INFLUENCE ON NUCLEAR ENERGY

The past few decades have been tumultuous for nuclear technology. The 1940s saw the rise of nuclear weaponry and the bombing of Hiroshima and Nagasaki, which had both physical and social consequences on the global scale. Yet, not all of the nuclear research done during this time was concerned with war. Chicago Pile-1, built by Enrico Fermi in 1942, was the first nuclear reactor in history, and proved the efficacy of nuclear energy (Tulenko, p. 203). The first commercial nuclear reactor in the United States was constructed in 1957 in Virginia, and today there are currently 57 nuclear power plants in operation in the United States. Combined, these plants generate 20% of the electricity demand of the United States without carbon dioxide or other greenhouse gas emissions (U.S. Energy Information Administration, 2020, para. 1-2).

Despite these benefits, nuclear energy has not yet reached acceptable levels of social acceptance. Disasters such as the failures of the Chernobyl Nuclear Power Plant in 1986 and the Fukushima Daiichi Nuclear Power Plant in 2011 highlight the grim consequences when technology fails. These reactors both encountered failures during operation, which resulted in the release of radioactive elements into the surrounding areas. While the Fukushima plant managed to employ fail-safes to mitigate the extent of failure, the Chernobyl plant underwent an explosive meltdown that rendered the surrounding area inhospitable. Despite improvements to safety and the numerous policies present to mitigate the chances of failure since these events, American polling on the public opinion of nuclear power done by papers such as Baron and Herzog (2020) have shown a downward trend of support, with sharp drops after these disasters (p. 2). The need to better understand the relationship nuclear technology has with society and various interconnected social groups is critical to improving public understanding and facilitating the implementation of nuclear energy.

NUCLEAR REACTOR SAFETY AS A SOCIAL TECHNOLOGY

To better understand the state of nuclear energy, it is important to establish a framework for its connection to society. Figure 2 is a depiction of nuclear energy through the lens of a social construction of technology (SCOT) framework as devised by Pinch and Bijker in 1987 (p. 22).

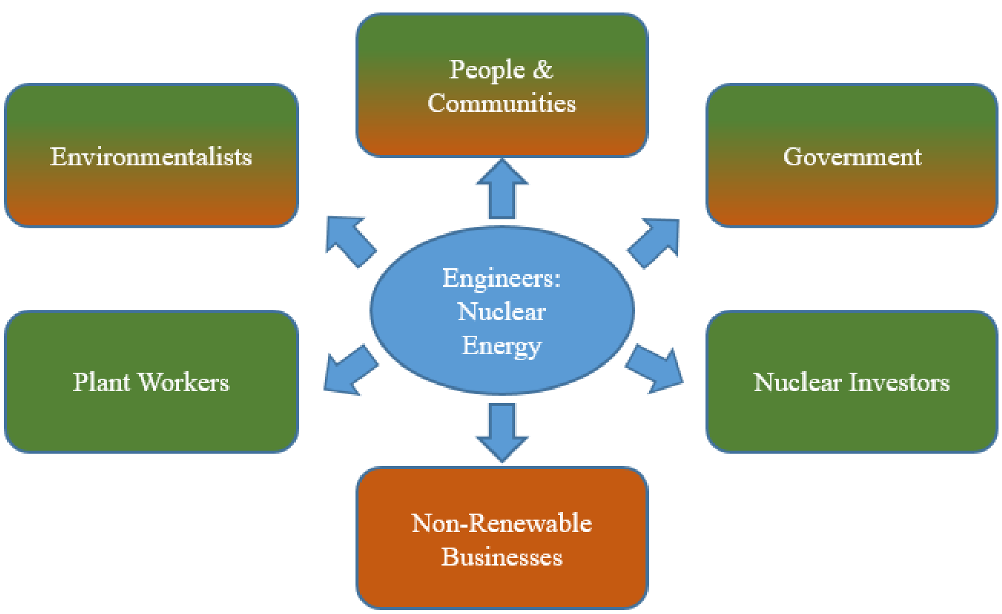

Figure 2: Nuclear energy SCOT model. The implementation of nuclear energy, headed by engineers, must appease the interests of all social groups involved (Adapted by Samuel Ong (2020) from Pinch and Bijker, 1984).

This framework shows that various social groups are dependent on nuclear energy as an artifact, and their collective interests must be kept in mind. This model also puts this responsibility in the hands of the engineers, who interact which each group separately and collaborate with them to reach an agreement. For each social group, nuclear energy has a different purpose; for some, such as the investors in the technology and the workers at the plant, it is an opportunity for profit and growth, while other groups like the corporations who manage traditional energy production see the rise of nuclear energy as a threat to their current standing. Each group brings something unique to the table that is necessary for the artifact to succeed, and often acts independently to achieve their goals. Like any other technology, public acceptance is highly reliant on available information. With the advent of the global inter-connected network, it is easier than ever to distribute knowledge, and this has continued to steer the course of this technology.

DIGITAL COMMUNICATION AS A MEANS TO INFLUENCE SOCIETY

The internet has facilitated the connection of countless people across the globe. Interactions and correspondence internationally can be done in seconds, and has revolutionized the idea of a social network. Nuclear technology has seen a great deal of coverage since its conception, most of which was focused primarily on weaponry and disasters (Perko et al., 2018, p. 527). This is because such events are immediately attention-grabbing due to their relevance to daily life. This has shaped a generation of opinions to be primarily nuclear-adverse, and is the primary reason why nuclear energy faces backlash globally. A study of the effects of Fukushima, one of the more recent nuclear disasters, by Y. Kim (2013) found that news about the disaster spread immediately and on a global scale, which forced political and corporate changes with respect to future nuclear development (p. 822-823). With social media, it has become trivial to voice these opinions and concerns to anyone and everyone. Figure 3 is a graphic of what digital communication has done to affect the opinions of social groups relevant to nuclear energy; opponents of nuclear energy have spread their ideals through various forms of digital communication, which has biased the opinions of others. Because views on nuclear technology have historically been negative, this has only furthered the anti-nuclear narrative.

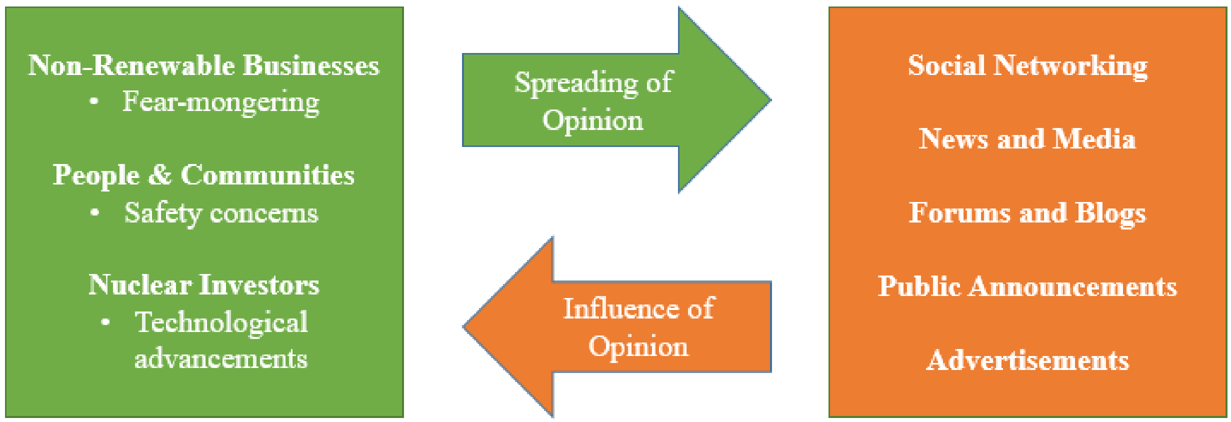

Figure 3: Representation of the effect of digital communication on opinion. Social groups spread their opinions through digital communication, which influences the opinions of others and converts them to their viewpoint (Ong, 2020).

Additionally, the rise of anonymity and sensationalism as a way to help news stand out has made disinformation and falsifications a common occurrence. The inability to fact-check news on the internet has influenced public opinion through disingenuous means. As said by D. Kim (2014), "there are some drawbacks on online public opinion on social media such as fraudulent and biased messages, witch hunting… and information distortion on social issues" (p. 373). With regards to nuclear energy, unsubstantiated rumors and lies about the extent of nuclear disasters such as Chernobyl have continued to contribute to negative ideas about the technology as a whole (Rahu, 2003, p. 295). However, digital communication can also help distribute information of the benefits of nuclear energy, and could be key to currying favor for its future (Kwok, Yeung, & Xu, 2017, p. 56-57).

The STS project will be a scholarly report that defines the relationship of nuclear energy and the social groups it influences, and how the opinions and motivations of these groups have shifted the public response as a whole to nuclear energy. The influence of communication technologies such as the media and social networking on the dispersion of information will also be explored, especially with regards to how it has been used by relevant social groups to spread information benefiting their cause. This will culminate into a definitive statement on the state of disinformation surrounding nuclear technology and remedial steps to help achieve public favor.

WORKS CITED

Amaral, J., Morais, C. (2010). Thorium and uranium extraction from rare earth elements in monazite sulfuric acid liquor through solvent extraction. *Minerals Engineering, 23,* 498-503.

Baron, J., Herzog, S. (2020). Public opinion on nuclear energy and nuclear weapons: The attitudinal nexus in the United States. *Energy Research & Social Science, 68,* 1-11

Brady, J. (2019). As nuclear waste piles up, private companies pitch new ways to store it. *National Public Radio.* Retrieved from https://www.npr.org/2019/04/30/716837443/as-nuclear-waste-piles-up-private-companies-pitch-new-ways-to-store-it

David, S., Huffer, E., Nifenecker, H. (2007). Thorium-uranium nuclear fuel cycle. *Europhysics News, 38(2),* 24-27.

Kim, D., Kim, J. (2014). Public opinion sensing and trend analysis on social media: a study of nuclear power on twitter. *International Journal of Multimedia and Ubiquitous Engineering, 9(11),* 373-384.

Kim, Y., Kim, M., Kim, W. (2013). Effect of the Fukushima nuclear disaster on global public acceptance of nuclear energy. *Energy Policy, 61,* 822-828.

Kwok, T., Yeung, C., Xu, Y. (2017). Swaying public opinion on nuclear energy: A field experiment in Hong Kong. *Utilities Policy, 46,* 48-57.

Lu, Y., Yang, Y., Zhang, P. (2012). Thermodynamic properties and structural stability of thorium dioxide. *Journal of Physics: Condensed Matter, 24(22),* 1-11.

National Aeronautics and Space Administration (n.d.) *Climate change: how do we know?* Retrieved from https://climate.nasa.gov/evidence/

Ong, S. (2020). *Nuclear energy SCOT model.* [Figure 2]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Ong, S. (2020). *Representation of the effect of digital communication on opinion.* [Figure 3]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Perko, T., Prezelj, I., Cantone, M., Oughton, D., Tomkiv, Y., Gallego, E. (2018). Fukushima through the prism of Chernobyl: How newspapers in Europe and Russia used past nuclear accidents. *Environmental Communication, 13(4),* 527-545.

Peter, S.C. (2018). Reduction of CO_2 to chemicals and fuels: a solution to global warming and energy crisis. *ACS Energy Letters, 3(7),* 1557-1561.

Pinch, T., Bijker, W. (1987). *The social construction of technological systems.* MIT Press.

Rahu, M. (2003). Health effects of the Chernobyl accident: fears, rumors and the truth. *European Journal of Cancer, 39,* 295-299.

Salehuddin, A. H., Ismail, A. F., Che Zainul Bahri, C., & Aziman, E. S. (2019). Economic analysis of thorium extraction from monazite. *Nuclear Engineering and Technology, 51*(2), 631-640.

Shaw, K. G. (1953). A process for separating thorium compounds from monazite sands. *Iowa State University Capstones, Theses, and Dissertations, 12740,* 1-185.

Tulenko, J. (2013). Nuclear reactor materials and fuels. *Nuclear energy, 1,* 203-214.

Union of Concerned Scientists (2017, December). *Coal and air pollution.* Retrieved from https://www.ucsusa.org/resources/coal-and-air-pollution#:~:text=Air%20pollution%20from%20coal%2Dfired,environmental%20and%20public%20health%20impacts.&text=Air%20pollution%20and%20global%20warming%20are%20two%20of%20the%20most%20serious.

U.S. Energy Information Administration (n.d.). *Frequently asked questions (FAQs).* Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

U.S. Energy Information Administration (2020). *Nuclear explained: U.S. nuclear industry*. Retrieved from https://www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php

Winter, A. (2020). *Process flow diagram for monazite refinement.* [Figure 1]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

World Nuclear Association (2017). *Thorium.* Retrieved from https://www.world2-nuclear.org/information-library/current-and-future-generation/thorium.aspx

Wu, Y., Chen, Z., Wang, Z., Chen, S., Ge, D., Chen, C., Jia, J., Li, Y., Jin, M., Zhou, T., Wang, F., Hu, L. (2019). Nuclear safety in the unexpected second nuclear era. *Proceedings of the National Academy of Sciences, 116(36),* 17673-17682.