An Emissions Case for US TRISO Fuel

NPRE 480 Mini Project 2

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Contents

1 Introduction

In part one, we introduced the concept of a once-through nuclear fuel cycle (NFC), and developed a series of simulations to probe the scope of design space for a fuel cycle that includes TRi-structural ISOtropic (TRISO) fuel in addition to Low Enriched Uranium (LEU) fuel, diagrammed in Figure 1.

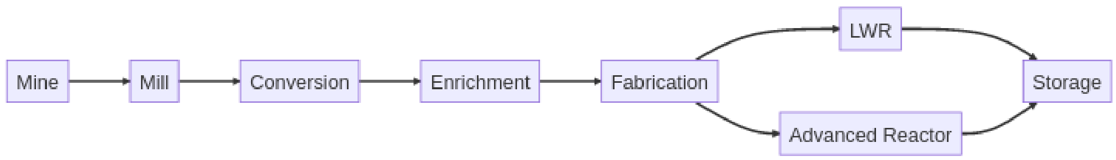

Figure 1: US Once-through Fuel Cycle

Our scenarios mix domestic and internationally sourced TRISO to fuel "Xe-100-like" reactors that are deployed as Light Water Reactor (LWR) models retire. This is not historical, or realistic, but we wanted to show how the transition is dominated by activity in the 2050 - 2075 range. Due to the much smaller energy output, the roughly 100 LWRs are replaced by 1500 of our generic advanced reactor model as shown in Figure 2.

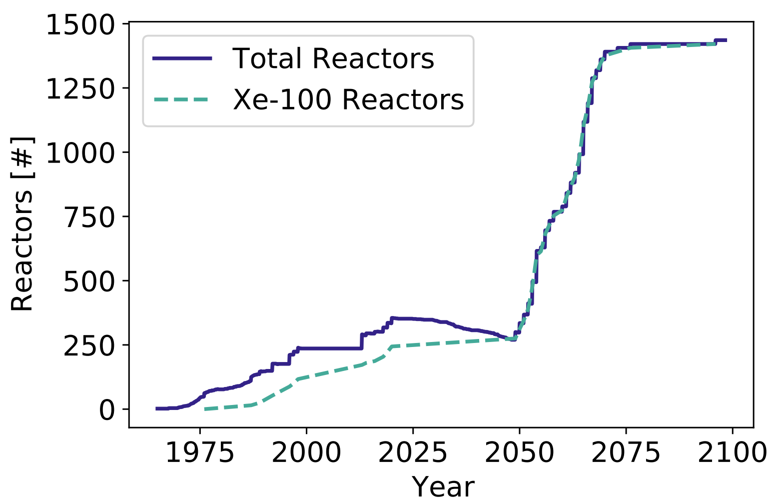

Figure 2: Cumulative number of reactors deployed

Our previous work is motivated by the increasing number of climate change-related events that face our nation every year. The United States (U.S.) Council on Environmental Quality from the Office of the Executive tracks census districts where there was at least one climate threshold exceeded (long-term measures of the number of extreme weather events, temperature increase, acidification trends, and Green House Gas (GHG) emissions). Looking at the U.S. mainland, these regions tend towards the western states, and (as we will discuss later) coincide with tribal lands, as shown in Figure 3.

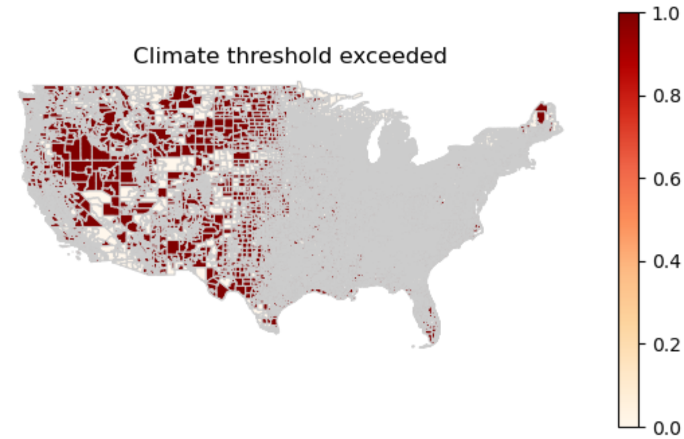

Figure 3: At least one climate threshold exceeded [1].

This trend is exacerbated in Alaska, as shown in Figure 4, where the a significant amount of the census districts have exceeded at least one climate threshold.

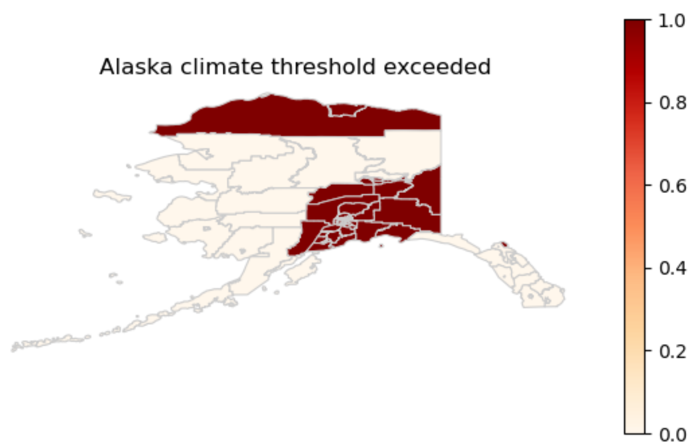

Figure 4: At least one climate threshold exceeded [1].

In this report we will develop our fuel transition model to incorporate added emissions from internationally-reliant NFCs. We will then discuss risk communication, and outreach to different communities on energy and climate topics as part of on-shoring a TRISO fuel cycle.

2 Transportation Emissions

In the study of energy security, the four (sometimes three) A's—Acceptability, Accessibility, Affordability, Availability—organize the study of an energy system or technology along easily understandable axes. In this report, we will examine the acceptability axis for TRISO-fueled reactors; specifically the emissions from the proposed fuel cycle scenarios. We will not be performing life cycle emissions calculations, instead focusing on emissions specifically employed to bring TRISO to the U.S. to isolate core differences in emissions and reduce the number of approximations we are making.

This work understands emissions as negatively impacting the acceptability axis of energy security, but the approach we employed could be adapted for changing valuations. One of the most significant areas of expansion to this approach would be to incorporate other metrics of acceptability, to better elucidate the full parameter space before collapsing it along a single axis.

2.1 Calculating Transactions

To get a rough estimate of the number of casks of fresh fuel needed to supply these newly deployed reactors, we can choose a cask type that could transport the TRISO and a generic ship model—we will create a maximum estimate by not attempting to convert the regulations for LEU to TRISO fuel. Our cask will be the Orano TN-B1 model [2]. From a test assembly letter to the U.S. Nuclear Regulatory Commission (NRC) [3], we get an idea of the loading of this specific cask model, which we combine with information from a presentation to the National Academies [4] on the Xe-100 reactor to get an estimate for the size of the pebbles a reactor of this type might use.

If we assume a 10% packing fraction, this gives us approximately 12892 pebbles per container, and 8 casks per ship[3]. The density of a pebble gives us a mass of 8.06728 kg. From our Cyclus simulations we can track all of the fresh TRISO fuel supplied to our advanced reactors, shown in Figure 5. We noted earlier that this transition isn't realistic, as we deploy advanced reactors at every decommissioning of a traditional LWR.

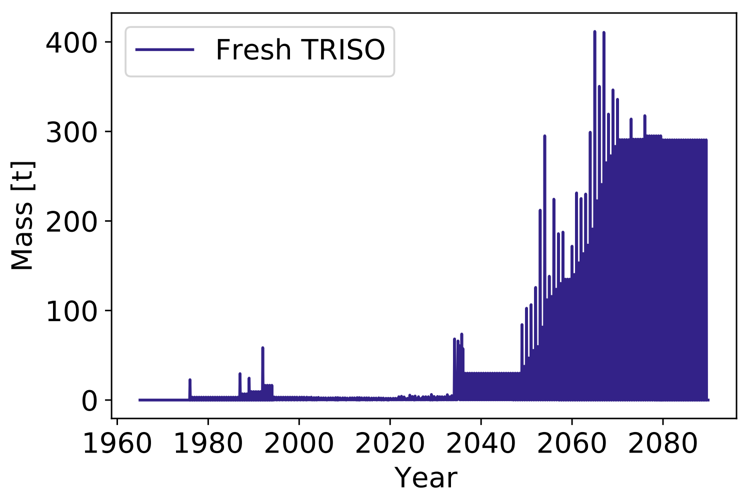

Figure 5: Mass of TRISO fuel supplied each year

2.2 Calculating Casks

We can now convert to casks, resulting in a very similar profile on a different scale in Figure 6. We have peaks in 2065 and 2067 at 18 casks. This work is not granular enough to consider individual plant shipments, instead we created a fleet-level analysis.

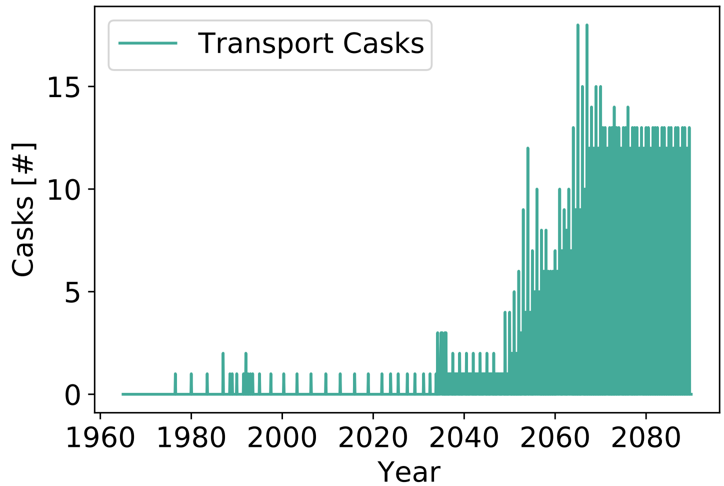

Figure 6: Casks of TRISO fuel shipped each year, with an additional 0.493% of a cask filled for the last shipment

2.3 Calculating Emissions

To complete this portion of the analysis, we will incorporate an estimate of 39.8 tons of fuel used per day to move a Panamax vessel [5], and we will place the source of international TRISO at the *Port of Le Harve* and the arrival point at the *Norfolk* port in Virginia. This route is operated by Hapag-Lloyd and takes 11 days and 10 hours for the ship [6] to traverse this distance. As such, we can plot the number of ship trips that an entirely international front-end fuel cycle would require in Figure 7

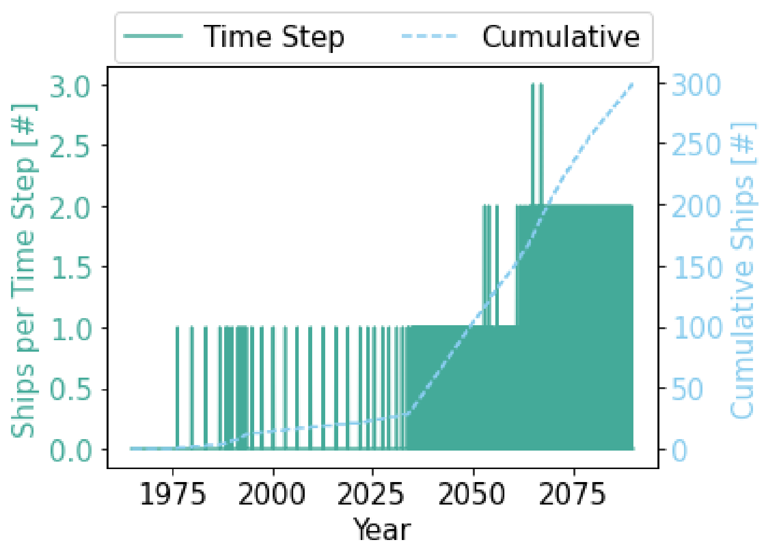

Figure 7: Ships of TRISO fuel

If we run these calculations for each scenario, we get cumulative additional emissions in tonnes.
Table 1 outlines only the additional emissions resulting from the overseas transportation of the fuel as it would likely be the largest source of additional emissions for an international component

Scenario	U.S. Enrichment [%]	Interntl. Enrichment [%]	Additional Transport. Emissions [t CO_2]
Scenario 1	100	0	0
Scenario 2	60	40	56139.23
Scenario 3	40	60	84208.84
Scenario 4	0	100	140348.067

Table 1: Scenario Emissions Summary

of the NFC, but there would be smaller contributors as well. On-shoring any amount of this part of the fuel cycle will not exist in a vacuum, but an early step will be communicating with potential host communities.

3 Risk Communication

In this section, we will briefly introduce risk communication by define it, clarify its goals, and introduce some important risk communication techniques.

Deploying High-Temperature Gas-cooled Reactor (HTGR) and its fuel production to the U.S. can reduce emission, but this also brings risk to various related communities. Aside from informing the public how much the HTGR can reduce carbon emission, eliminating the general misunderstandings of risk of nuclear reactors is another essential way to increase the acceptability of TRISO. The public eager to know how radiation may affect their lives, but the complex methods experts use to evaluate risks create a gap between experts and ordinary people so deep that for the public, doubt and fear prevails when it comes to fission power. Risk communication, a study of expert-public interaction based on how humans convey their reactions and responses to threats, is a bridge over this gap.

According to the risk communication report by NRC, risk communication is "an interactive process used in talking or writing about topics that cause concern about health, safety, security, or the environment" [7]. Experts defines risk as:

$$\mathbf{risk} = \mathbf{Probability} \times \mathbf{Consequences}$$

to identify risks with higher priority and allocate resources accordingly. However, the public views risk as a sum of actual disaster and factors that may upset them according to Dr. Peter Sandman's equation:

$$\mathbf{risk} = \mathbf{Hazard} + \mathbf{Outrage}$$

This fundamental difference in defining risk between experts and the public requires close handling to make dialogue meaningful. Risk communication is the method to connect risk management, risk analysis, and the public so that stakeholders can understand and appreciate the project.

Communication can have various purposes. Clearly identifying the goal of dialogue is the basis of choosing communication strategies and reaching a mutual-satisfied conclusion. Some of the common purposes of risk communication involves providing information, gathering information, building trust and credibility, seeking involvement, and influencing behaviors and perceptions about risk.

Once the goal is clarified, we can proceed to determine techniques for effective dialogue. The most important aspect of risk communication is to learn about the stakeholders. Stakeholders includes organizations, individuals, generally concerned groups, and media. Concerns of these groups will differ based on the location of the program. Proximity of public services and food sources, population density, past interaction with nuclear projects, and economic impacts are all factors affecting how the stakeholders will response to the program. A research on local demographics, ethnic background, media and political activity will be extremely helpful in forming a communication strategy.

Another important technique in nuclear-related risk communication is how to build trust. For nuclear industry, the public is always skeptical because of past disasters such as Fukushima incident in in 2011 and Chernobyl accident in 1986. Under this environment, it is extremely important to keep open and honest while providing evidence of increasing safety measure of reactors to regain trust from the public.

4 Community

In the previous section, we reviewed the importance of risk communication and some of its common practices. In this section, we will use the risk communication techniques onto our project, examining how to organize dialogue with Native American community about bringing TRISO production to the U.S. to maximize mutual benefit.

4.1 Historical Radiation Pollution on Native American Reservations

The major domestic uranium deposit overlaps with many Native American reservations. Thus, if we want to set up proper front-end facilities of nuclear fuel cycle to satisfy the massive growth in demand of uranium in the future, it is essential to cooperate with Native Americans. However, as one of the most marginalized group in the U.S., Native American community suffered severely from nuclear-related programs in the past. Their attitude towards a new nuclear project will be skeptical, even hostile.

Extremely vulnerable to radiation pollution, Native American community was exposed to proportionally high dosage of radiation due to nuclear mining, nuclear tests, and waste dump. According to U.S. Environmental Protection Agency (EPA), in Navajo Nation, there are over 500 abandoned uranium mines with high level of radiation, poisoning the air and drinking water in the reserve[8]. From 1951 to 1992, more than 200 cases of nuclear tests were done in the Nevada Test Site (NTS), releasing radioactive particles containing I-131, Cs-131, Sm-90, and other actinides to the atmosphere, which then fell on nearby Native American reservations, contaminating their food sources[9]. Besides, the federal government took advantage of the poor economical condition of the reserves, and lured tribes such as the Mescalero Apache and Skull Valley Goshute as dump site of high-level radioactive waste exchange for money[10]. Moreover, Native American community lacked the professional and financial resource to properly understand and handle the radioactive wastes on their land, and no research or monitoring was provided to them, let alone assistance.

4.2 Necessity of Communication with Native American Community

Because of damage due to nuclear wastes, many Native Americans believes nuclear projects on their land is an act of cultural destruction from the government [9]. However, as shown in Fig.8 and 9, some of the major uranium deposition overlaps with Native American reservations such as in Navajo Nation between Arizona and New Mexico and in Wind River Indian Reservation in Wyoming. To reach uranium independence in the U.S., it is necessary to work with the local Native American community to rebuild their trust in uranium mining projects.

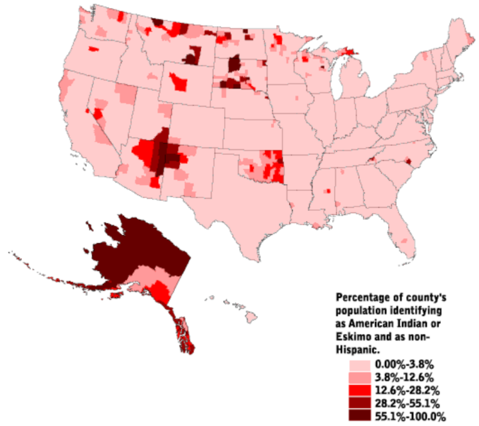

Figure 8: American Indian Population according to 2000 Census
[11]

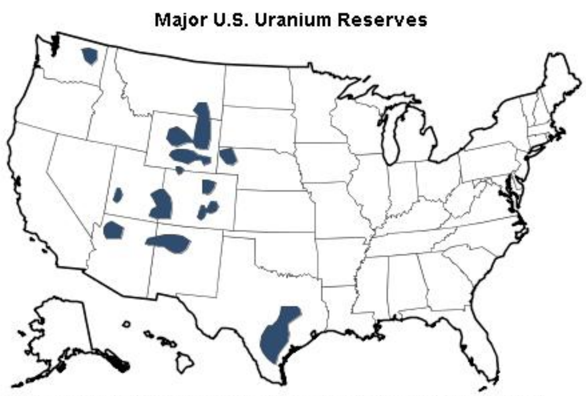

Figure 9: Major U.S. Uranium Reserves
[12]

4.3 Measures of Risk Communication

Calling back to our previous discussion of risk communication and considering the history of irresponsible mishandling of radioactive wastes in Native American Reserves, the most essential goal of dialogue should be the reestablishment of trust between local Native people and outside nuclear mining promoters such as and federal government. To restore confidence, the NRC report[7] recommends take responsibility and apologize. For example, according to a report on uranium contamination in Navajo Reservation by the U.S. Government Accountability Office (GAO), four million tons of uranium ore were extracted from mines on the Navajo reservation, primarily for developing nuclear weapons[13]. The abandoned mine released radioactive particles to the air and polluted local water. In 2007, The federal government took responsibility by starting an inter-departmental plan to evaluate the risk of these mines. In 2018, forty-six mines were prioritized and their cleanup are underway[14]. Though no official apology was released from the Congress, a realistic plan for remedying mistakes is still essential towards mutual-trust.

Beyond cleaning legacy contamination, Quigley's paper suggested four long-term measurements for managing the health risk. The government should provide resources so that the Native communities can build their own health infrastructure. Besides, a community exposure profile should be recorded to better study the impact of contamination. Moreover, the government should teach local people how to properly handle nuclear wastes. Finally, community members should be included in developing a plan for future hazard management[9]. These measurement will not only restore trust, but also secure local community's involvement in future.

Once the trust is restored, we can shift the goal of communication towards influencing behavior and perception by addressing the new regulations of NRC about uranium mining and ensuring prioritized access to electricity generated from HTGR. Under Title 10, Part 40, of the Code of Federal Regulations (10 CFR Part 40), NRC will regulate the disposal of radioactive tailing and make sure the mine will be handled properly. Besides, to gain support from the local communities, we should ensure the reactor burning uranium mined on their land will serve the Native American community first. 21% of the homes in Navajo Nation does not have access to electricity[15] either because the electricity grid could not reach to them or because they cannot afford the electricity bill. Small modular HTGR is the perfect solution of this scenario. Setting up a local small modular reactor can provide electricity to local families without building expensive electricity transport infrastructure. Furthermore, we can subsidize the electricity price generated by the nuclear reactors to make it affordable. Combining with the intrinsic safety measure of HTGR, it is likely that Native American community will support the uranium mining because the uranium will be safely mined and used. Uranium will light up their community and improve quality of life instead of making bombs and slowly killing people near the test site.

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Acronyms

10 CFR Part 40 Title 10, Part 40, of the Code of Federal Regulations. 8

EPA U.S. Environmental Protection Agency. 6

GAO U.S. Government Accountability Office. 7

GHG Green House Gas. 1

HTGR High-Temperature Gas-cooled Reactor. 5, 8

LEU Low Enriched Uranium. 1, 3

LWR Light Water Reactor. 1, 3

NFC nuclear fuel cycle. 1, 2, 5

NRC U.S. Nuclear Regulatory Commission. 3, 5, 7, 8

NTS Nevada Test Site. 6

TRISO TRi-structural ISOtropic. 1–6

U.S. United States. 1, 3, 5, 6