More Power, Less Nukes: How Thorium Energy Could Decrease the Current Threat Level of Nuclear Warfare

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ABSTRACT

The argument I present is that greater investment in thorium energy will result in a decrease in the threat of nuclear warfare and a revolution in clean energy production. The first and most important piece of evidence to aid this argument is recognizing a side effect of thorium's non-fissile nature: it cannot be used as a weapon. To further emphasize how revolutionary thorium is, under 3 metric tons of thorium can power cities with populations of over 22 million for over a year. These would be major population centers such as Mexico City, Mexico, or Cairo, Egypt, to provide a sense of perspective. In short, nuclear weapons proliferation in reference to thorium energy is scientifically impossible. This work will give a new definition to the long-misunderstood name of nuclear energy. The reputation of such a pure and powerful form of energy has too long been sullied by preventable tragedies. Should thorium be further researched, and the correct steps to build thorium energy infrastructures be taken, the world would have a less pollutant, and even more effective form of energy. According to the Thorium Energy Alliance, thorium is not only safer to mine but more environmentally friendly. In addition, thorium is not concentrated heavily in one geographic location. This means that instead of importing non-renewable energy sources from foreign governments, thorium may be mined and turned into energy domestically, creating a new industry and thousands of well-paying jobs for citizens. The International Atomic Energy Agency (IAEA) coordinates cooperative action between 176 member states to limit the proliferation of nuclear weapons. Moreover, the IAEA encourages sharing information between experts in the field of nuclear sciences regardless of nationality. Perpetuating shared values and goals such as these encourages further state interaction and strengthens international bonds.

1. INTRODUCTION

Since the advent of nuclear studies into both atomic weapons and energy alike, plutonium and uranium were by far the most common materials to use. The first nuclear bomb, tested in Alamogordo, New Mexico code-named "Trinity", was a plutonium implosion device; similarly, the Obninsk nuclear power plant in Obninsk, Russia used uranium as its primary fuel source. Nuclear power was born as an afterthought of nuclear weapons. The same materials are being used for the ultimate displays of production and destruction. The Second World War and the Cold War demanded more immediate attention than responsibly sourced energy ever could.

Thorium emerged as a viable alternative to the constraints of the cumbersome and morally questionable nature of uranium or plutonium by scientists such as Dr. Homi Bhabha and his 3-stages of nuclear power program for India. As a result, India is currently at the forefront of thorium-based power innovations, but they are among the few nations to highly invest in this. However, thorium and the science behind it have proved to be something greater than an alternative, rather, it is a successor. Thorium has been recognized as a vastly superior material by the most acclaimed scientists of Europe and Asia, as well as proving its availability to every continent on Earth as a resource for energy production. This paper explores the potential of thorium-based nuclear energy as a solution to the current threat level of nuclear warfare. The goal is to provide a comprehensive analysis of the potential of thorium-based nuclear energy, assess what that would mean for environmentally friendly energy production on a large scale, and finally exemplify these scientific facts through a political perspective on an international scale. When the innate political aspects of thorium energy work alongside the scientific observations of the material, thorium can decrease the threat level of nuclear warfare and provide a sustainable and efficient source of energy for the future.

2. AVAILABILITY OF NUCLEAR MATERIALS AND THE RESOURCE CURSE

First and foremost, the concentration of uranium and plutonium in the Earth's crust is limited in concentration and geopolitical availability [1]. Of the 59 nations which hold uranium reserves, 53% of the reasonably assured total of 3,524,900 tons on Earth are located in only 3 countries: Australia, Kazakhstan, and Canada [2]. While the exact measurements of plutonium reserves are not publicly disclosed due to individual national security concerns, estimates show that the largest plutonium reserves are in the following countries by order of estimated tons: the United States, Russia, France, Japan, and Canada. Based on the data collected by Albright and Kramer, these 5 nations hold 71% of the world's 1,780 tonnes of plutonium reserves [3].

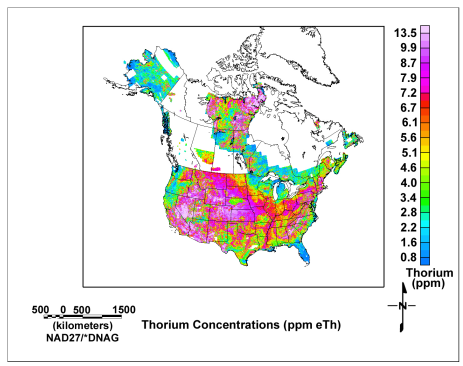


Figure 1

Thorium is much more evenly spread out around the world than uranium or plutonium. This is because thorium is a naturally occurring element in Earth's crust, while uranium and plutonium must go through multiple purification cycles [4]. It naturally occurs across a wide variety of landscapes, most of the naturally occurring thorium in India is concentrated in the sandy beaches on its southern and eastern coasts [5]. Conversely, Canada has no year-round warm beaches like India; the densest concentrations of thorium in Canada exist in the Nunavut Territory, along the Hudson Bay [6]. Thorium density varies in amount but is typical throughout the world, 74 countries have at least 1,000 reserves of thorium, every country on the African continent has thorium reserves of this magnitude or more. A display of thorium concentration in the United States and Canada can be seen in Figure 1.

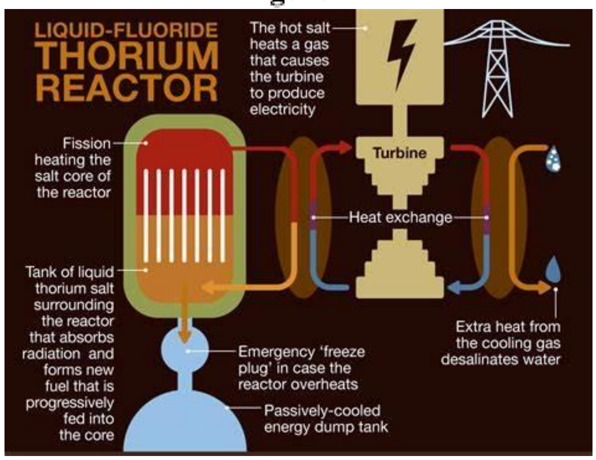
As can be observed in both uranium and plutonium reserves, cases of select nations stockpiling the majority of these nuclear resources are omnipresent. The massive disparity between the "have-and-have-nots" of uranium and plutonium resources is much more prominent than crude oil reserves. The 3 nations with the largest oil reserves are Venezuela, Saudi Arabia, and Canada. They account for less than half of the world's overall total, 44.6% [7].

For such a resource more evenly distributed throughout all nations on every continent, national interests to attain oil have sparked multiple wars throughout the late 20th and 21st centuries, the endless conflict across the Middle East and unrest in Venezuela are a testament to this. When a nation is rich in resources of worldwide demand, they are often the target of subjugation by foreign powers for the extraction of said resource. This is called the "Resource Curse" or "Paradox of Plenty" and leads to rises in intrastate violence, government instability, workers' rights abuses, currency devaluation, and the likeliness to seek nuclear weapons to varying degrees [8]. If non-proliferation is the goal, then the national exclusivities of uranium, plutonium, and fossil fuels are incompetent solutions.

3. NATIONAL AND INTERNATIONAL CONCERNS

Without strict adherence to established codes of conduct and procedures, human error and company oversight is liable to birth a disaster of truly epic magnitude such as the meltdown of the Chernobyl power plant in 1986 or the hellish afflictions suffered by Hisashi Ouchi at the Tokaimura power plant in 1999. Notably, this is an especially grave concern for power plants operating with uranium and plutonium. Uranium and plutonium reactors are designed to sustain nuclear chain reactions, this is the most dangerous and deadly stage of energy production. These concerns are quelled by thorium's coolant restraint and its resistance to meltdowns. Not only is

Figure 2



Thorium safer for the average worker, but more attractive for states to build both domestically and abroad.

Figure 2 exemplifies the process of a Liquid Fluoride Thorium Reactor (LFTR). This is the sequence of events for pressurized water reactors (PWRs) and boiling water reactors (BWR) as well, the most common types of reactors that use thorium. These three reactor types do not allow nuclear chain reactions. Thorium also contains no fissile material, meaning the nuclear reaction can be stopped instantaneously [9]. This does not hinder thorium's energy production, as a thorium reactor can produce efficiency levels as high as 98% while current nuclear technologies achieve an efficiency rate of around 5% [10]. Of course, this results in low nuclear waste, great profitability compared to the current standard, and a constantly reliable source.

It is non-fissile, meltdown-proof, and extremely efficient. All of these components make it an attractive energy project for domestic development, but what incentives do states have to develop these machines abroad? Recent advancements in the mass production of Molten Salt Reactors (MSR) offer a waste burner the size of a 40-foot shipping container capable of producing 100 MWth [11]. Its size relative to a shipping container is important to highlight how mobile this machine is.

Indeed, thorium energy compared to uranium and plutonium is outstanding in production, but it continues to impress as an instrument of non-proliferation and an inspiration for international cooperation scientifically, commercially, and diplomatically.

3.1 THORIUM WASTE DISPOSAL AND HALF LIFE

Thorium is unlike other nuclear materials because most of its density is kept throughout the nuclear fuel cycle. From the beginning of the cycle in mining to fabrication, and the utilization of prepared materials for energy production in reactors, thorium keeps its existing material while uranium and plutonium are diluted to around 3-5% of their original mass for the sake of purification standards [9].

Thorium is exempt from this purification process. It can be used directly as a fuel from the moment it is harvested from the Earth. Other positive factors supplement thorium as a clean energy source, such as its short half-life: only 500 years [9]. While 500 years is certainly a long time, it pails in comparison to uranium or plutonium, which each have half-lives of around 10,000 years. This chemical reaction is different because of thorium's lack of U-238, which turns into U-239 upon absorbing high-flying neutrons inside reactors. These neutrons are responsible for exceedingly long half-lives.

3.2 MONEY TALKS: COST, EFFICIENCY, AND ANTI-PROLIFERATION

Appeals to science, morality, and rationale are useful to interest states in ensuing this form of energy, but the most impactful contentions for states to adopt thorium energy for the sake of decreasing nuclear weapons threat levels is the fact that it is not possible to construct a nuclear weapon from thorium at all [12]. Unlike uranium power, thorium does not need a plutonium change to initiate energy creation. Plutonium is the most paramount ingredient in the creation of a nuclear weapon, acting as the detonation initiator of an atomic bomb. Further, thorium's complete lack of fissile material gives it additional protection against harmful gamma rays from U-232, so should a malicious actor attempt to siphon any material able to be made into a nuclear weapon from thorium the process would be highly challenging and tedious [12]. Even if the separation of thorium and trace amounts of fissile material such as protactinium were successful, the half-life of the derived Pa-233 is a laughable 27 days [13].

As for efficiency, there is no match for thorium's performance. According to Nobel prize laureate Carlo Rubbia at the European Organization for Nuclear Research (CERN), one ton of

Figure 3

City, Country	Population	Kilowatt-hours (KWh) consumption per year	Estimated Thorium needed per year
Tokyo, Japan	~37.2 million	~78.4 Billion KWh	~7.1 tons
São Paulo, Brazil	~22.6 million	~40 Billion KWh	~3.6 tons
Mexico City, Mexico	~22.5 million	~27.6 Billion KWh	~2.5 tons
Cairo, Egypt	~22.1 million	~52.7 Billion KWh	~4.7 tons
Instanbul, Turkey	~15.8 million	~93.3 Billion KWh	~8.4 tons

*Data from the Tokyo Electric Power Company, Brazilian Electricity Regulatory Agency, Mexican Energy Regulatory Commission, Egyptian Electricity Holding Company, and the Turkish Electricity Transmission Corporation. All reports are from 2020.

thorium can produce as much energy as 200 tons of uranium or 3.5 million tons of coal [14] [15]. To best exemplify this revolutionary claim, a collection of notable population centers across the world shows a rough estimate of the amount of thorium needed to power the centers for one year in Figure 3.

The greatest priority of a nation is itself. Via thorium energy, nations would become partially or fully energy independent. Nations which have achieved energy independence or are close to it are innately more open to international cooperation because the likelihood of conflicts due to foreign energy supplies are diminished and the exportation of energy to other powers is available [16].

The cost of using thorium energy is equally as inspiring. Given that the international marketplace and trade, in general, fluctuate frequently due to a myriad of factors such as current demand, interstate relations, and others, concrete costs cannot be cemented. However, studies from the Journal of Nuclear Engineering and Technology estimate that the lowest production costs for the mass production of thorium, which includes mining, transit, quality and safety assurance, and other such preparations to use the material for energy production are between $501-$553 (USD) for a 10-kilogram production run [17]. Additional economic data from the World Nuclear Association assists the previous study, stating that 10 kilograms of uranium going through the same process costs $2,740-3,040 (USD) [18].

4. NUCLEAR ENERGY'S HAND IN INTERNATIONAL COOPERATION

Nuclear energy was born from a desire to create the most destructive weapon ever produced. Its past is undeniable. This dichotomy between science that is meant to build and science meant to destroy may sometimes be used by nations and their world leaders to justify conflict between rivals. On the opposite end of the spectrum, when politics and science work together for the greater good of humanity, their contributions to foreign policy and international cooperation are immeasurable. This is called scientific diplomacy [19]. Examples of this practice in effect are the International Space Station, the European Organization for Nuclear Research (CERN), The Paris Agreement on Climate Change, and the global efforts to eradicate the disease of Polio. Scientific diplomacy proves that nations are open and willing to work alongside other powers to achieve a common goal, however, these nations need to agree on what that common goal is. Individual national interests, security, and alliances often aid and complicate this process.

International relationships and the myriad factors complicating them are inherently unruly and unpredictable. This portion of the paper attempts to calculate the effects on countries that work together for nuclear-related sciences, what countries are eligible to be calculated, and the benefits they receive from doing so. Luckily, several constants in world politics can help to uncover relevant patterns in this area of research.

Figure 4.

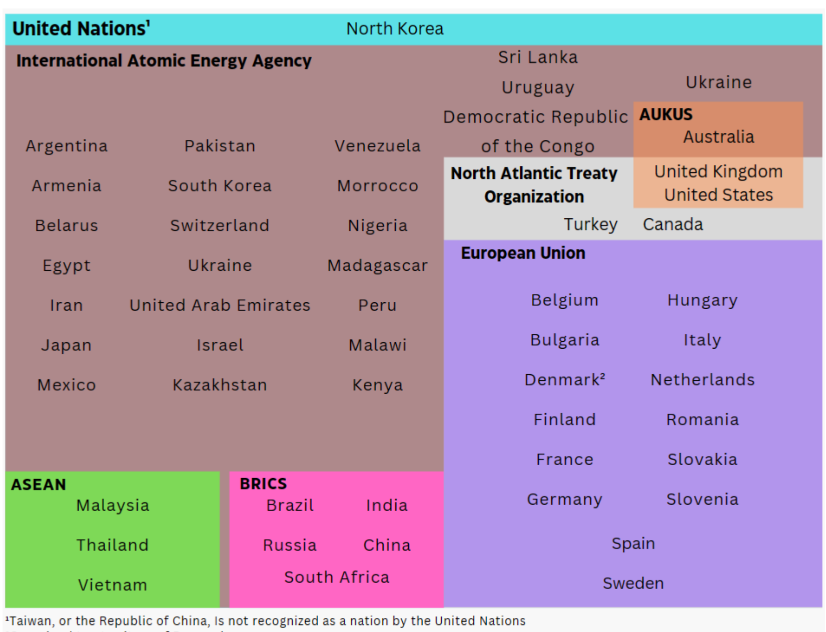
Constant	Explanation
Allegiances to International Organizations	When countries subscribe to international organizations, they pledge allegiance to follow the values of it and are incentivized to behave cordially with fellow member states. Recognizing which countries are in or out of select organizations can point to likely cooperations.
Causes of Scientific Diplomacy With Thorium	Why would countries want to work together with thorium, specifically? Does cooperation between two or more powers on nuclear energy work out in the real world? How do thorium energy facilities fair today? This section answers these questions with appropriate proof.
Effects of Scientific Diplomacy Through Thorium	Can the effects of cooperative thorium energy projects increase jobs, foster safe exchanges, and actually increase national autonomy? Yes, the evidence in this section proves it.

Observing allegiance to international organizations has shown to be most useful in detailing the combination of IOs certain nations are/are not members of. Observing the effects of scientific diplomacy on certain nations concerning nuclear studies verifies the correlation between international cooperation, nuclear advancement, and decreasing the nuclear war threat level. Presenting the logistical benefits to nations pursuing thorium energy shows the financial, political, and social gains to be enjoyed from the investment in thorium. All measurements highlight the actions of individual nations and their particular interests in non-aggression, nuclear energy, and scientific cooperation.

Before evaluations based on these factors could be measured, 53 nation-states have been identified as eligible for this study because one or more of the following criteria are met: uses nuclear energy, has nuclear weapons, and/or has a high content of raw nuclear resources in its territory [20]. Likewise, the selection of the specific organizations is not meant to showcase all organizations relevant to international nuclear policy but meant to highlight certain types of organizations and their goals. A select few of these states will be used as examples and not every nation will be observed for the sake of brevity.

4.1 ALLEGIANCES TO INTERNATIONAL ORGANIZATIONS

For this study, seven organizations pose the most significant relevance to observe, namely: the United Nations (UN), the International Atomic Energy Agency (IAEA), the North Atlantic Treaty Organization (NATO), the European Union (EU), the Association of Southeast Asian Nations (ASEAN), the BRICS Alliance, and the AUKUS Security Pact. These organizations may center around trade, security, unbiased monitoring, diplomacy, or any combination of such purposes. While each may offer different incentives, all share a promise of exclusivity and a shared goal [21]. The interconnections of these nations are exemplified in Figure 5.



The United Nations remains a constant in this evaluation, containing 193 of the 195 sovereign states on Earth. This is the bare minimum of showing that a nation is open to international dialogue and cooperation, all of the aforementioned 53 nations are UN members. The first exemption of one state from further international cooperation is North Korea, as it is not a member of the IAEA, due to its isolationist nature, this is not surprising.

The remaining 52 nations are members of the United Nations and IAEA, meaning that they subscribe to each organization's goals to outline international legislation for the regulation of peace and hold further proliferation of nuclear weapons under high scrutiny. Arguably, the most committed among these nations are Kazakhstan and Ukraine, which dismantled their nuclear program after their independence. These two nations show that states can commit to the "greater good" despite the immense loss of military power.

The remaining organizations listed divide the pool of eligible nations greatly. Likewise, the interest of these organizations varies, as purely defensive agreements such as NATO and AUKUS promise that the participating nations will come to the defense of one another. These organizations exist as a cornerstone of the "Nuclear Umbrella Theory", stating nuclear weapons-possessing states will come to the aid of a non-nuclear ally [22]. This is especially true for Australia, which is guaranteed nuclear protection by the US and UK. Collections of nations focused on diplomacy through free and relaxed trade are shown through ASEAN, as none of these are nuclear weapons states, but heavily involve themselves in nuclear energy for the sake of profitability and the improvement of their nations. Finally, the European Union and BRICS represent international unions between multiple states which share a common interest and work together militarily, economically, and in many other ways to achieve that goal. It is important to note that BRICS is significantly less unified than the European Union.

In all, this graph is meant to exemplify that commitments in multiple IOs sometimes coincide and clash with one another, but nonetheless are avenues for cooperation.

4.2 CAUSES OF SCIENTIFIC DIPLOMACY

National collaborations on a grand scale are difficult to execute because each country must have the incentive to benefit from an exchange. This is known as the "Collective Action Problem", which posits that it is easier or more desirable to free-ride on the efforts of others rather than contribute to the completion of the goal [23]. To overcome this obstacle, countries must not only reconcile with the other party or parties involved but justify the action to have a greater benefit than inaction. This manifests itself in multiple ways, all unique to each country. For instance, should Brazil want to create an organization consisting of all of the nations rich in nuclear resources and exportation of said resources, Australia may contest this because their population would oppose the decision and their international relations with nations such as the United States or the United Kingdom could be jeopardized. In this scenario, thorium could be used as leverage to quell public fears that the material could be used for weapons and put significantly less stress on Australian-United States-United Kingdom relations.

Multiple instances of these cooperative examples in scientific diplomacy through nuclear studies exist today. For example, Krško 1 is a jointly-owned nuclear power plant between the nations of Slovenia and Croatia since 1981, before the collapse of the Republic of Yugoslavia [24]. The ownership of the plant is split exactly 50/50, with cooperation running so smoothly for over 30 years, plans for Krško 2 have been approved for construction and are expected to be finished by 2027. The United States and Canada tout an even more vibrant exchange and ownership of nuclear plants, cooperative actions between governments entities like the U.S. Department of Energy and the Canadian Ministry of Energy and private companies such as the Ontario Power Generation Corporation and GE Hitachi are frequent and involve thorium in their dealings more often as time goes on [25].

India boasts the largest contributions to thorium energy, as they have the world's largest reserves [26]. Indian physicist Homi Bhabha introduced a three-stage nuclear power program for in 1954 to take advantage of India's abundant supply of resources. To achieve energy independence for such a large and populous country, Dr. Bhabha hypothesized that India ought to adopt uranium fuel for Heavy Water Reactors as the first step, Fast Breeder Reactors as the second, and a combination of uranium and thorium fuel sources as the last step [27]. As the final and most advanced step in the plan, thorium was seen as the key to granting India energy independence. China, Canada, and the United States are all exploring the possibilities of creating a commercial-scale thorium-fueled reactor [28]. This is the shared goal that is needed for scientific diplomacy to take place. However, these states must evaluate the alliances, collective actions, data, resources, and commitments of other nations and assess if the benefits are worth it

4.3 EFFECTS OF SCIENTIFIC DIPLOMACY THROUGH THORIUM

All possible effects of furthering international cooperation into thorium-based energy point toward the decrease and deincentivization of nuclear weapons proliferation. As previously mentioned, thorium is not fissile, so making a nuclear weapon from it is not possible. This would decrease the suspicion of new nuclear weapons programs being fostered in countries attempting to utilize nuclear power. Moreover, international action in thorium-based energy production would increase autonomy, as exemplified by Dr. Bhabha's three steps. Should a country mine its own resources, refine its products, use the material to power its own cities, and deposit the waste appropriately, nations could improve how their economy functions and succeed. This is true because the nations with the highest GDPs and most diverse economies are also the most connected to international organizations and trade [29].

In addition, the jobs created for these countries via accepting thorium energy would employ hundreds of thousands. According to the IAEA in 2021, 600,000 direct jobs are attributed to the nuclear industry worldwide [30]. These jobs range from requiring the highest skills and expertise in the field to low-skilled, entry-level positions. Of these jobs created, many deal with international scientific research, only serving to increase the number of interactions and achievements between groups of nations.

5. POLICY RECOMMENDATIONS

Recommendation 1: The United Nations hosts discussions in branches about nuclear energy/weapons to encourage multinational cooperation with thorium-based nuclear energy technology.

This recommendation would involve the International Atomic Energy Agency (IAEA), the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Office of Disarmament Affairs (UNODA), the United Nations Development Program (UNDP), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). While this process is slow and unlikely to succeed, the point is its discussion and bringing awareness to the nations of the UN.

Recommendation 2: Countries should pursue scientific cooperation with other nations on their own regarding thorium-based nuclear energy.
Recommendation 3: Nations with the processes available to process nuclear material should seek alliances with nations that are rich in nuclear raw materials.

6. CONCLUSION

Progress has been made in answering the overarching questions posed by the paper:

- How is thorium a better nuclear fuel than uranium or plutonium?
    - Thorium is more abundant, denser, cheaper to produce, more effective, safer, and unable to make into a nuclear weapon due to its non-fissile nature, unlike uranium or plutonium.
- How can thorium-based energy strengthen bonds between countries?
    - Through the creation of jobs, the exportation of resources, the cooperative efforts of scientists, and the co-ownership of power plants.
- Can thorium-based energy forge new relationships?
    - The Krško 1 power plant outlived the fall of Yugoslavia and preceded the foundation of the two states which co-own it. Although the Krško 1 does not run on thorium, this shows the power nuclear energy has on international relations in general.
- Is thorium better for the environment compared to uranium or plutonium?
    - Yes, because thorium has a much shorter half-life and plants cannot melt down, unlike uranium and plutonium.
- Does thorium decrease the likelihood of countries issuing interstate nuclear threats, or threats in general?
    - Yes, because thorium cannot be made into a nuclear weapon, the material is evidence in and of itself to decrease threats.

Thorium-based nuclear power represents an auspicious solution to the problems of climate change and threats of nuclear warfare. The potential and prosperity thorium poses as a nuclear fuel source are many: its safety, its abundance, its efficiency, and its low environmental impact for a nuclear fuel source is incomparable. Should the countries of the world band together to harness the power of thorium, humanity's impact on the environment would lessen without the need for overly invasive energy forfeitures and needless threats of nuclear annihilation would decrease, creating a safer, more cooperative future.

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