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Threats of Nuclear Power and Plans for the Future

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Problem Statement

Global Environmental Issue

The United States alone emits an immense amount of carbon dioxide into the atmosphere. It is extremely likely that the rising global temperature trends since the mid-20th century is dominantly due to human activity. No scientific organization of national or international standing disputes this. Furthermore, the US department of Defense has officially stated that climate change poses a serious national security threat. In light of all that, the United States are committed to significantly reducing carbon emissions in regards to the Paris Climate Agreement. Given that in 2015 alone 2 billion metric tons of carbon dioxide were released from electricity generation only and fossil fuels are responsible for over 99% of these emissions, it would be pretty ideal to start replacing fossil fuel power plants with alternative energy sources like nuclear energy.

Ideally, we'd have a source that doesn't emit CO2 and is consistently reliable; this is known as a baseload energy source. In this context, nuclear energy is the main alternative energy source that works. Yet, unlike its fickle counterparts, **nuclear energy is subjected to hostile attitudes** adopted by a number of governments in the world which restrict the building or continual operation of power plants. Fear for Chernobyl and Fukushima-type catastrophes exacerbate the unpopularity of going nuclear. The US, currently the world's largest producer, relies on nuclear energy for **20% of its overall electricity generation**. Yet there has historically been a strong anti-nuclear movement in the US, and the sentiment is still somewhat present today, as demonstrated by closures of nuclear power plants and stances held by prominent political figures such as Vermont Senator Bernie Sanders. In order to assess whether such notoriety is deserved, we need to learn about the physics of nuclear power and compare the statistics of its supposed dangers with that of existing energy sources.

In 2002, nuclear power supplied 20% of United States and 17% of world electricity consumption. Experts project worldwide electricity consumption will increase substantially in the coming decades, especially in the developing world, accompanying economic growth and social progress. However, official forecasts call for a mere 5% increase in nuclear electricity generating capacity worldwide by 2020 (and even this is questionable), while electricity use could grow by as much as 75%. These projections entail little new nuclear plant construction and reflect both economic considerations and growing anti-nuclear sentiment in key countries. The limited prospects for nuclear power today are attributable, ultimately, to four unresolved problems:

❖ Costs: nuclear power has higher overall lifetime costs compared to natural gas with combined cycle turbine technology (CCGT) and coal, at least in the absence of a carbon tax or an equivalent "cap and trade" mechanism for reducing carbon emissions.

❖ Safety: nuclear power has perceived adverse safety, environmental, and health effects, heightened by the 1979 Three Mile Island and 1986 Chernobyl reactor accidents, but also by accidents at fuel cycle facilities in the United States, Russia, and Japan. There is also growing concern about the safe and secure transportation of nuclear materials and the security of nuclear facilities from terrorist attack.

❖ Proliferation: nuclear power entails potential security risks, notably the possible misuse of commercial or associated nuclear facilities and operations to acquire technology or materials as a precursor to the acquisition of a nuclear weapons capability. Fuel cycles that involve the chemical reprocessing of spent fuel to separate weapons-usable plutonium and uranium enrichment technologies are of special concern, especially as nuclear power spreads around the world.

❖ Waste: nuclear power has unresolved challenges in long-term management of radioactive wastes. The United States and other countries have yet to implement final disposition of spent fuel or high level radioactive waste streams created at various stages of the nuclear fuel cycle. Since these radioactive wastes present some danger to present and future generations, the public and its elected representatives, as well as prospective investors in nuclear power plants, properly expect continuing and substantial progress towards solution to the waste disposal problem. Successful operation of the planned disposal facility at Yucca Mountain would ease, but not solve, the waste issue for the U.S. and other countries if nuclear power expands substantially.

Threats, risks and danger

The word *nuclear* alone conjures up a parade of terrors: the sinister radiation, the whiff of apocalypse, and the tendency to go boom. Those are the obvious sci-fi horrors. But nuclear power comes with plenty of other risks that aren't so obvious: the hazards of uranium mining, the fouled water, and the radioactive waste. So do these horrors mean nuclear power shouldn't be part of our tool kit for fighting climate change? After all, it doesn't produce greenhouse gases. That's why some have pushed to keep existing nuclear power plants open, and even build more. When it comes to nuclear power, the risks appear right from the **beginning of the process with uranium mining** and they continue to pop up throughout the nuclear life cycle, from enrichment and reactor operation to the radioactive waste at the end. It's a process fraught with hazards.

Risk of mining to general health

During World War II, the U.S. government began digging for uranium throughout the Southwest to create the first atomic bombs. Officials saw early on that the work posed a hazard but they didn't tell the miners or the people living in the surrounding communities. After all, they were making a secret weapon. Mining today is much safer than it was during the Cold War. It takes at least a decade to complete all the environmental- and social-impact assessments needed before starting a new mine. Studies have found increased risks ranging from lung cancer to diabetes in communities near uranium mines (though there's not enough evidence to prove that mining is the cause). Other studies have suggested that modern-day miners are more likely to get sick than white-collar workers. Mining of all kinds scars the land and puts people in danger. Coal and tar sands mining cause the same problems on a larger scale. Even renewable power relies on people unearthing the cobalt, indium, and other materials for solar panels and batteries.

There are bits of radioactive material scattered throughout the earth's crust, and when you excavate tons and tons of rock, you're going to get exposed to a lot of it. As a result, the people digging up the elements required to make solar panels collectively get a little more radiation than the people mining an equivalent amount of uranium. Blasting out the iron ore needed to build wind turbines and generate the same amount of power exposes miners to a little less radiation.

Accidents

In the middle of the night on April 26, 1986, workers shut off the safety systems to run a test on the Chernobyl plant, in the Soviet Ukraine. Something went wrong. The reactor ramped up to 100 times its normal power, heating the steam in its pressurized system until the reactor exploded through the roof of the building around it. A fisherman reported seeing a blue flash in the sky from the reactor. People 60 miles away felt the ground shake. Two workers on site were killed by the explosion, and others would die from radiation exposure. Scandinavian countries began reporting higher radioactivity readings.

There have been three high-profile accidents since nuclear plants started running in 1951, and Chernobyl was the worst. Besides the two killed by the explosion, 28 workers died from acute radiation poisoning. Estimates of the total number of deaths in the years since varies wildly as a result of basic methodological disagreements over how much radiation increases your likelihood of cancer. The World Health Organization's review came up with an estimate of 4,000 to 9,000 deaths.

And then there's the Fukushima meltdown, which caused no direct fatalities. A 2017 report from the United Nations Scientific Committee on the Effects of Atomic Radiation concluded that health effects to the general public from radiation were almost nil. The committee expects to see two or three more cancerous tumors among the 173 workers most exposed to radiation. The evacuation of 110,000 people, however, led to 1,600 deaths. Scientists reassessed the disaster response and concluded that, even with the risk of radiation, locals would have been better off staying put.

Three Mile Island, a reactor just south of Harrisburg, Pennsylvania, partially melted down in 1978. No one was killed in the accident, and there was only a small release of radiation. The U.S. Nuclear Regulatory Commission says the accident had "no detectable health effects on plant workers or the public." But it may have been enough to increase the risk of thyroid cancer among people exposed, according to one study.

Nuclear Reactor Meltdown

Inside the core of a nuclear reactor are thousands of long, thin fuel rods made of zirconium alloy that contain uranium. When a reactor is turned on, the uranium nuclei undergo nuclear fission, splitting into lighter nuclei and producing heat and neutrons. The neutrons can create a self-sustaining chain reaction by causing nearby uranium nuclei to split, too. Fresh water flows around the fuel rods, keeping the fuel rods from overheating and also producing steam for a turbine.

But if not enough water flows into the reactor's core, the fuel rods will boil the water away faster than it can be replaced, and the water level will decrease. Even when the reactor is turned off so nuclear reactions no longer occur, the fuel rods **remain extremely radioactive and hot** and need to be cooled by water for an extended period of time. Without enough water, the fuel rods get so hot that they melt. If they begin to **melt the nuclear reactor core** and the **steel containment vessel**, and release radiation into the environment, **nuclear meltdown** occurs.

Roughly around 2012, Tepco's has had **continuous struggle** to contain and cool the fuel rods and those series of incidents highlight just how energetic uranium fission reactions are and how challenging to control. Of course, that level of energy is exactly why we use nuclear energy – it is incredibly efficient as a source of power, and it creates very few emissions and carries a laudable safety record to boot

Japan's cooling problems
When the earthquake struck Japan, three of the six reactors (Reactors 4, 5, and 6) at the Fukushima power plant were already off for routine inspections. Earthquake tremors triggered the automatic shutdown of the other three reactors, Reactors 1, 2, and 3 (along with eight other nuclear reactors at other power plants). To stop the chain reaction, control rods that absorb neutrons were inserted in between the fuel rods. But the fuel rods are still hot, since radioactive byproducts of past fission reactions continue to produce heat. When the earthquake tore down the power lines, the plant's main cooling system stopped working. As a backup measure, diesel generators turned on to spray the fuel rods with coolant. But the tsunami that occurred shortly after the earthquake was larger than the plant's designers had anticipated, and water flowed over the retaining wall and into the area with the generators, causing them to fail. The next backup measure for cooling the fuel rods was a battery system, but the batteries lasted only a few hours. Later, technicians brought in mobile generators and also attempted to inject seawater into the nuclear reactors, which makes them permanently unusable but could help prevent a complete meltdown.

While the nuclear technicians searched for better cooling options, the water levels continued to decrease, exposing the tops of the fuel rods. Pressure also began building in some of the reactors. So far, at least three explosions have occurred in Reactors 1, 2, and 3. The explosions happened when the fuel rods began to melt and release gases that reacted with the surrounding steam, producing hydrogen. To release some pressure and prevent explosions, technicians vented some of the reactors, which also released some radioactive material into the environment. Officials have said that the pressure in Reactor 2 dropped significantly after the explosion there, suggesting that the explosion breached the steel containment structure - the reactor's "last resort" for containing leaked radiation.
Also, a fire ignited at Reactor 4, thought to be caused by a large pile of spent fuel rods in a pond. Spent fuel rods need to be kept fully submerged in water for cooling, but the lack of water has left some of the rods partially exposed. Smoke from the fire temporarily increased radiation levels around the reactor, so preventing future fires is very important. The Fukushima plant has seven ponds of spent fuel rods from the past few decades. By some estimates, there may be as many as half a million spent fuel rods that are still radioactive and could catch fire if not kept cool.

Japanese officials have stated that radiation around the nuclear reactors has risen to the level where it would adversely affect a person's health. Officials have implemented a 20-km (12-mile)-radius evacuation zone, and have advised people to stay indoors. The US has told its citizens living in the area to stay at least 50 miles away from the power plant. Some people have been taking prophylactic iodine

as a safety measure; consuming this non-radioactive iodine before exposure to radioactive iodine can fill a person's thyroid and hopefully prevent absorption of the radioactive variety. Fortunately, westerly winds have so far blown much of the radioactive material out to sea.
Overall, because the extreme events that caused the cooling problems are so rare and unexpected, it's difficult to predict exactly what will happen next for Japan's nuclear plants.

Plans for the Future

Thorium for an alternative
Thorium is a basic element of nature, like Iron and Uranium. Like Uranium, its properties allow it to be used to fuel a nuclear chain reaction that can run a power plant and make electricity (among other things). Thorium itself will not split and release energy. Rather, when it is exposed to neutrons, it will undergo a series of nuclear reactions until it eventually emerges as an isotope of uranium called U-233, which will readily split and release energy next time it absorbs a neutron. Thorium is therefore called *fertile*, whereas U-233 is called *fissile*.

Reactors that use thorium are operating on what's called the Thorium-Uranium (Th-U) fuel cycle. The vast majority of existing or proposed nuclear reactors, however, use enriched uranium (U-235) or reprocessed plutonium (Pu-239) as fuel (in the Uranium-Plutonium cycle), and only a handful have used thorium. Current and exotic designs can theoretically accommodate thorium.

Benefits of Thorium

- **Thorium cycles exclusively allow thermal breeder reactors**. More neutrons are released per neutron absorbed in the fuel in a traditional (thermal) type of reactor. This means that if the fuel is reprocessed, reactors could be fueled without mining any additional U-235 for reactivity boosts, which means the nuclear fuel resources on Earth can be extended by 2 orders of magnitude without some of the complications of fast reactors. Thermal breeding is perhaps best suited for Molten Salt Reactors, which are discussed on their own page as well as in summary below.
- **The Th-U fuel cycle does not irradiate Uranium-238 and therefore does not produce transuranic (bigger than uranium) atoms** like Plutonium, Americium, Curium, etc. These transuranics are the major health concern of long-term nuclear waste. Thus, Th-U waste will be less toxic on the 10,000+ year time scale.
- **Thorium is more abundant in Earth's crust than Uranium**, at a concentration of 0.0006% vs. 0.00018% for Uranium. This is often cited as a key benefit, but if you look at the known reserves of economically extractable Thorium vs. Uranium, you'll find that they are both nearly identical. Also, substantial Uranium is found dissolved in sea-water, whereas there is 86,000x less Thorium in there. If closed fuel cycles or breeding ever become mainstream, this benefit will be irrelevant because both the Th-U and the U-Pu fuel cycles will last us well into the tens of thousands of years, which is about as long as modern history.

Downsides of Thorium

- **We don't have as much experience with Th.** The nuclear industry is quite conservative, and the biggest problem with Thorium is that we are lacking in operational experience with it. When money is at stake, it's difficult to get people to change from the norm.
- **Thorium fuel is a bit harder to prepare.** Thorium dioxide melts at 550 degrees higher temperatures than traditional Uranium dioxide, so very high temperatures are required to produce high-quality solid fuel. Additionally, Th is quite inert, making it difficult to chemically process. This is irrelevant for fluid-fueled reactors discussed below.
- **Irradiated Thorium is more dangerously radioactive in the short term.** The Th-U cycle invariably produces some U-232, which decays to Tl-208, which has a 2.6 MeV gamma ray decay mode.

The Nuclear Reactor

One especially cool possibility suitable for the thermal-breeding capability of the Th-U fuel cycle is the molten salt reactor (MSR), or as one particular MSR is commonly known on the internet, the Liquid Fluoride Thorium Reactors (LFTR). In these, fuel is not cast into pellets, but is rather dissolved in a vat of liquid salt. The chain reaction heats the salt, which naturally convects through a heat exchanger to bring the heat out to a turbine and make electricity. Online chemical processing removes fission product neutron poisons and allows online refueling (eliminating the need to shut down for fuel management, etc.). None of these reactors operate today, but Oak Ridge had a test reactor of this type in the 1960s called the Molten Salt Reactor Experiment (MSRE). The MSRE successfully proved that the concept has merit and can be operated for extended amounts of time. It competed with the liquid metal cooled fast breeder reactors (LMFBRs) for federal funding and lost out. These reactors could be extremely safe, proliferation resistant, resource efficient, environmentally superior (to traditional nukes, as well as to fossil fuel obviously), and even cheaper.

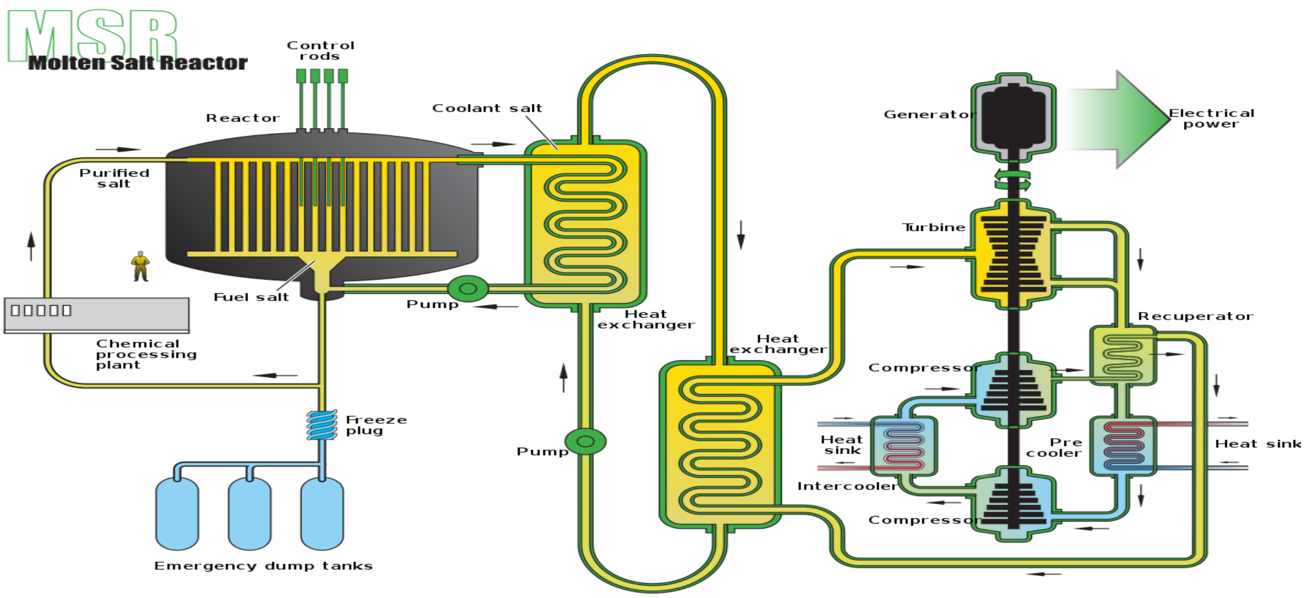

Figure shows a brief description of how MSR works. (Taken from Wikipedia, https://en.wikipedia.org/wiki/Molten_salt_reactor)

Why Thorium is a better alternative

According to engineer and cofounder of Copenhagen Atomics Thomas Jam Pedersen, it doesn't take a whole lot of Thorium to generate a massive amount of energy supply. A ball the size of a marble can supply the energy of person's entire life time. And considering that it is an element in the periodic table, it is relatively easy to find. In fact, in every mining project, many miners find abundance of Thorium laying around, but not many bat an eye because they don't know what to do with it. Mining a marble sized thorium will only cost $100 and it is estimated that it only cost $1 per year for an entire energy supply for a person. It is also estimated that Thorium may be able to generate (through Uranium-233 that could be produced from it) eight times the amount of energy per unit mass compared to (natural) Uranium. In the much debated issue of waste generation also, Thorium has a relative advantage. It produces waste that is relatively less toxic due to the absence of minor actinides (that are associated with Uranium). At the same time, it is acknowledged that the long-lived high-level waste from Uranium, especially in light of the Indian strategy of adopting the closed fuel cycle involving reprocessing for the recovery of Plutonium and Uranium, can be effectively managed using technologies **available today.** Indian nuclear experts tell us that the relatively small volumes of such waste (long-term storage space of less than a quarter of the size of a football field is adequate for the estimated waste from a 1000 MWe plant) can be safely stored after vitrification for hundreds of years without causing any risk to the environment or the people.

Another key point to this is the machine used to convert thorium into energy. As stated above, organization like Oak RIdge have developed Molten Salt Reactors to convert Thorium into a clean energy. According to Thomas Pedersen, these motors are one of the **safest reactors in existence** which is a huge advantage considering the amount of reactors malfunction in recent history. You may be wondering why the government haven't put a thought into funding a research to this project, but it is simple to see why they haven't or wouldn't. The underlying assumption is that Thorium is a stable element and still radioactive, but **it cannot be used to create weapons**. Unlike Uranium, which is always on a tight-rope walk between being a power source and finding destructive applications, Thorium bombs just cannot be made. Here history steps in. It must be remembered that much of the current civil nuclear applications are direct offshoots of the military nuclear technologies of the Cold War period. So, the first significant outcome of nuclear technology was the Manhattan Project during the Second World War, which ultimately culminated in the Hiroshima and Nagasaki bombing of 1945 by the U.S. Considering that the United State of America have put so much funding and research into developing nuclear weapons for military purposes, it would be very difficult to shift into Thorium production by the American government.

Production in India

Being one of the largest owners of Thorium, and also being amongst the nations which will see the highest surge in power demand with its growth, the opportunity is for India to pursue its existing nuclear programme with a special focus on research and development on the Thorium route as the long term sustainable option, which we are already undertaking. For this purpose, it is imperative to continue to implement the current Indian plan of making use of the uranium and plutonium-based fuel cycle technologies as well as irradiate larger amounts of Thorium in fast reactors to breed Uranium-233 fuel as it graduates to the Thorium-based plants. It is noteworthy that the Indian plan for an Advanced Heavy Water Reactor (AHWR) (shown in fig. 2) is an important step to launch early commencement of Thorium utilisation in India, while considerable further efforts to use Thorium in both thermal and fast reactors would be essential to harness sustainable energy from Thorium-generated Uranium-233. Various technologies for Thorium-based plants are already being developed and deployed on a test basis across the world including in India, which have a promising future. These include first breeding it to fissile Uranium-233 isotope in the conventional reactors or the Molten Salt Reactors (MSR), like the one tested by Oak Ridge, which use salts to trap the fissile material and do not react with air or burn in air or water. In this technology, the operational pressure is near the ordinary atmospheric pressure, and hence the **cost of construction is low and there is no risk of a pressure explosion**.

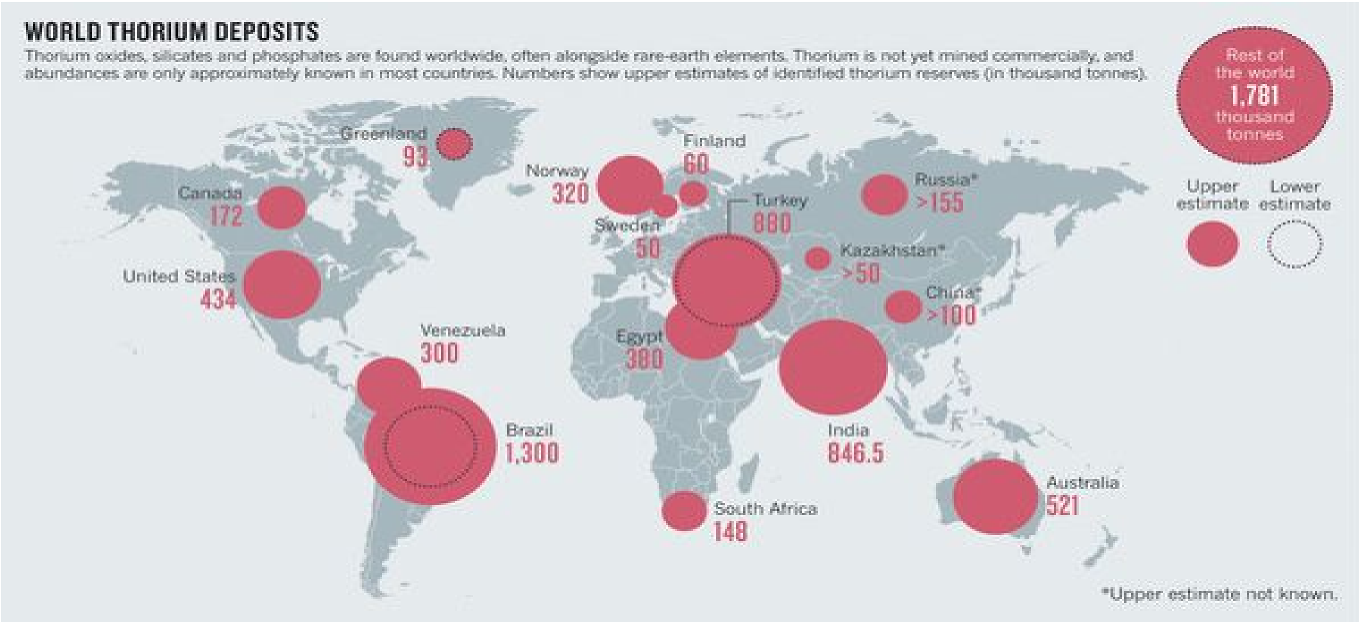

Figure 1 shows distribution of Thorium around the world.

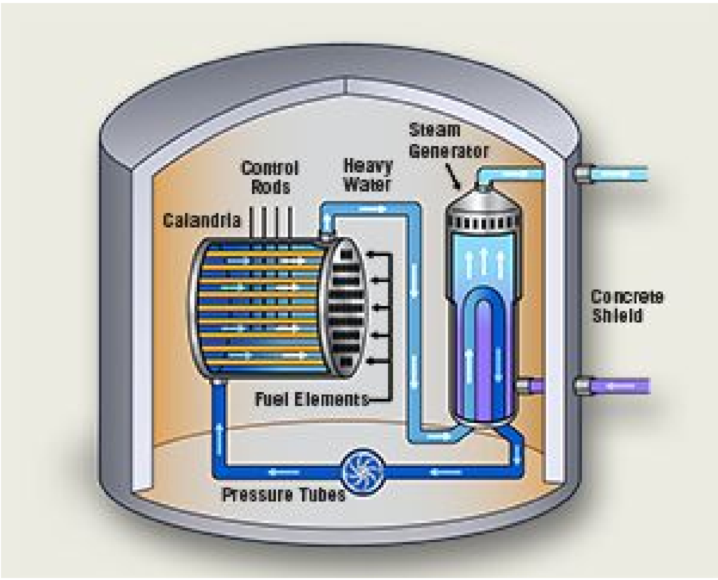

Figure 2. Advanced Heavy Water Reactor (AHWR)

Evaluation

A significantly large quantity of highly active nuclear material exists, and will continue to exist in the form of nuclear armaments — which was the mother programme of the nuclear energy programme. In 2010, there were about 22,000 nuclear warheads spanning at least nine countries of the world, and 8,000 of them are in active state, carrying a risk far greater than controlled nuclear power reactors. If the argument of risk is to be used to eliminate the peaceful energy generation programme, then the nuclear opposition factions must first direct their efforts at Washington and Moscow, the owners of 90 per cent of the world's nuclear warheads, to disband their nuclear arsenal — which is, by design, intended to be hostile. Would that happen? Unlikely, at least in the foreseeable future. Our aim should be to **minimise the risks associated with nuclear power**. The power of the nucleus is mighty and the **future of humanity lies in harnessing it in a safe and efficient manner**.

In the years to come, it will fuel not only our earth-based needs but also our space missions and perhaps even our civilisation's reach to other planets for habitation. Our current nuclear projects will expand into better and safer materials, like Thorium, and later on, into better reactions like fusion, which once completely developed, will be able to generate hundreds of times more of power than current fission methods. **Affordable, clean and abundant energy** provided by nuclear sources is our gateway to a future that is healthy, learned and connected — a future that will span deep into space and crosses the boundaries of current human imagination.

References

"Reconsidering the Risks of Nuclear Power." *Science in the News*, 25 Oct. 2016, sitn.hms.harvard.edu/flash/2016/reconsidering-risks-nuclear-power/.

"Making Safe Nuclear Power from Thorium | Thomas Jam Pedersen | TEDxCopenhagen." *YouTube*, YouTube, 15 Nov. 2016, www.youtube.com/watch?v=tHO1ebNxhVI.

"Thorium-Based Nuclear Power." *Wikipedia*, Wikimedia Foundation, 16 Oct. 2018 en.wikipedia.org/wiki/Thorium-based_nuclear_power.

Sorensen, Kirk. "What's the Difference Between Thorium and Uranium Nuclear Reactors?" *Machine Design*, 10 Oct. 2016, www.machinedesign.com/whats-difference-between/whats-difference-between-thorium-and-uranium-nuclear-reactors.

Research, Casey. "Why Not Thorium?" *MINING.com*, 15 Feb. 2012 www.mining.com/why-not-thorium/.

Ashley, Steven. "Thorium Could Power the next Generation of Nuclear Reactors." *New Scientist*, 25 Aug. 2017, www.newscientist.com/article/2145535-thorium-could-power-the-next-generation-of-nuclear-reactors/.

Whitwam, Ryan. "New Molten Salt Thorium Reactor Powers Up for First Time in Decades." *ExtremeTech*, 28 Aug. 2017, www.extremetech.com/extreme/254692-new-molten-salt-thorium-reactor-first-time-decades.

Kalam, Abdul, and Singh. "Nuclear Power Is Our Gateway to a Prosperous Future." *The Hindu*, The Hindu, 31 July 2016, www.thehindu.com/opinion/op-ed/nuclear-power-is-our-gateway-to-a-prosperous-future/article2601471.ece

"Backgrounder on Nuclear Reactor Risk." *United States Nuclear Regulatory Commission - Protecting People and the Environment*, 10 July 2018, www.nrc.gov/reading-rm/doc-collections/fact-sheets/reactor-risk.html.

Johnson, Nathanael. "Meltdowns, Waste, and War: Here Are the Real Risks of Nuclear." *Grist*, Grist, 15 Oct. 2018, grist.org/article/nuclear-is-scary-lets-face-those-fears/.

"Dirty, Dangerous and Expensive: The Truth About Nuclear Power." *Physicians for Social Responsibility*, 31 July 2009, www.psr.org/blog/resource/dirty-dangerous-and-expensive-the-truth-about-nuclear-power/.

Zyga, Lisa. "How Does a Nuclear Meltdown Work? ." *Phys.org - News and Articles on Science and Technology*, 17 Mar. 2011, phys.org/news/2011-03-nuclear-meltdown-video.html.