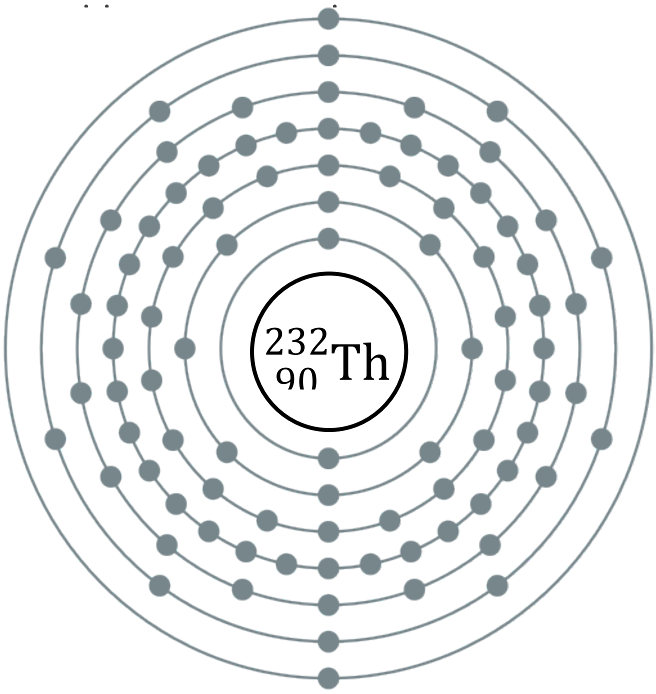
September 2019

An investigation into Liquid Fluoride Thorium Reactors

The following inquiry was created by a Year 11 student for a High School audience; its contents are all referenced in the bibliography. The inquiry is focused on promoting the use of Liquid Fluoride Thorium Reactors (LFTRs) over Pressurised Water Reactors (PWRs). Please note that the author had to comply to a 2000-word limit; consequently, its contents had to be concise, this caused multiple facts about both PWRs and LFTRS to be unmentioned. The inquiry has concluded that LFTRs have multiple benefits over PWRs, including their increased modularity, safety and lowered costs. Therefore, it's recommended that LFTRs become the prevalent method used



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Claim:

"The application of nuclear technology for either power, industrial or medical applications is as safe, environmentally friendly or cost effective as possible."

Rationale:

"Between 1990-2016 electricity demand doubled. It is expected to roughly double again by 2050" this means that humanity "requires a low carbon" viable energy source (World Nuclear Association, 2018). The claim that *"the application of nuclear technology for either power, industrial or medical applications is as safe, environmentally friendly or cost-effective as possible"* has 3 possible areas of investigation; either analysing how safe, eco-friendly or cost-effective nuclear applications are.

The process of power generation produces unwanted wastes; these harm the environment and are currently poorly disposed of (US EPA, 2019). Consequently, global action is being taken, i.e. CO_2 emissions are being minimised, due to the relationship between CO_2 and global warming (ucsusa.org, 2017). For nuclear technology to be environmentally friendly it should have a minimal environmental impact.

A cost-effective reactor will work towards repaying its investment; i.e. by utilising abundant materials. In comparison to fossil fuels nuclear reactors are equally as cost effective, the dividing factor is their environmental impact (Appendix 7).

Stating that nuclear technology is safe is an extremely controversial topic, this is because of the previous meltdowns and failures experienced. Globally there are three distinguishable failures: Fukushima, Chernobyl, and Three Mile Island; these failures all involved a partial or full core meltdown (World Nuclear Association, 2019). A safe reactor should produce a marginal amount of toxins and have a passive -autonomous- safety system. Current reactors are still functioning with similar designs from the Fukushima, Chernobyl and Three Mile Island incidents.

The damage those reactors caused, means the claim cannot be supported; therefore, different reactors will be investigated. Alvin Weinberg was a nuclear physicist who administrated the Oak Ridge National Laboratory; under his guidance twelve reactors were designed, constructed and operated (Roberto & Nestor, 2014), these included the PWR and LFTR. In a conference (2004) Weinberg expressed his fondness for Molten Salt Reactors (MSRs) over other reactors (Weinberg, 2017). Consequently, the proposed research question is:

The inventor of the Pressurised Water Reactor (PWR) was correct, PWR's are too risky; can Liquid Fluoride Thorium Reactors (LFTR) replace their popular use, becoming the prevalent method used to produce humanities energy requirements?

If LFTRs are concluded to possess the ability to replace the use of PWRs the claims criterion will be satisfied.

Nuclear Reactors:

Nuclear reactors function by maintaining stable developments of energy through nuclear fission reactions. Energy sourced from Uranium fuelled reactors are generally the mass defect produced through the reaction of ^{235}U,

$$^{235}_{92}U + ^{1}_{0}n = ^{236}_{92}U = \begin{cases} (85\% \text{ of the time}) \text{fission reactions i.e.} ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + \text{energy} \\ (15\% \text{ of the time}) \; ^{236}_{92}U + \gamma \end{cases}$$

(WNA, 2018). 15% of all reactions within Uranium fuelled reactors release gamma emissions. Gamma waves (photons) present both internal and external hazards for humans (DOE, n.d.), and unlike alpha or beta emissions gamma waves only become immobile when concrete, steel or lead barriers are used (Appendix 3).

The uniqueness of each nuclear reactor model is distinguished through the reactors design features, i.e. the fuel/coolant used. The majority of (the 448) reactors in operation globally are large scale nuclear reactors, the predominantly used model is the Pressurised Water Reactor (World Nuclear Association, 2018).

Pressurised Water Reactor (PWR)

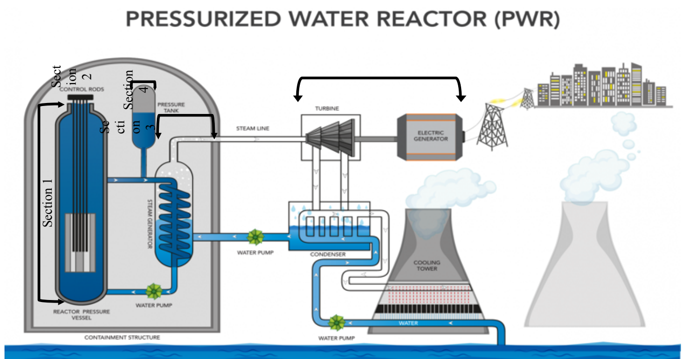


Figure 1.1 Graphic by Sarah Harman | U.S. Department of Energy

PWR's are currently the leading generators of nuclear energy globally, the models generated 7% of the total nuclear energy used globally-11% (Appendix 2). PWR's use majorly the exact technology the first commercial reactors utilised; originally developed throughout the 1940s and 50s.

Natural Uranium (235) is enriched from 0.7%→4% for nuclear fuel, these pellets are moulded into fuel rods; they are reflected in section 1 (of figure 1.1) among the control rods. PWR's require enriched Uranium to function, a surplus of neutrons would occur if natural uranium was used (NRC, 2019). During 2018 53,498T of natural Uranium was mined globally; only 3,745T was naturally fissile, and approximately 50,000T of Uranium required enrichment (Appendix 4).

Light water is pressurised at 155 atm (standard atmosphere), this is so the water doesn't boil and functions to cool and moderate the chain reactions; section 1&2 of figure 1.1. Steam is consequently produced (section 3) and through the use of turbines electricity is generated; as reflected in section 4 (IN2P3, n.d.).

Most PWR's functioning were built decades ago, their safety systems are ineffective (ucsusa.org, 2008). The predominantly used PWR is being analysed, not to be confused with the modern reactors being generated with effective safety systems. Active safety systems are associated with the original PWR's; they require both onsite power and an operator to guide the system to ensure the safety of the reactor (Milonopoulos, Blandford & Wit, 2014).

The third most significant nuclear accident to date was the Three Mile Island failure; it was a PWR. The relief valve failed to shut, causing a loss of the coolant, consequently the reactor overheated. Had the operator onsite seen the issue the partial meltdown wouldn't have occurred (ucalgary.ca, 2018); human error led the active safety system to fail.

Small Modular Reactor (SMR):

Small modular reactors (SMRs) are the smaller, more modular versions of reactors. The International Atomic Energy Agency (IAEA) state SMRs have outputs of "under 300MWe (MegaWatt-Electrical) (WNA, 2019). SMRs largely use new reactor designs; utilising graphite, gases, molten salts and other materials to fuel and cool their reactors.

SMR models vary due to their fuel/coolant designs; (WNA, 2019). Molten Salt Reactors (MSRs) operated during the 1960s, their research reappeared in the 2000's (WNA, 2018).

Liquid Fluoride Thorium Reactor (LFTR)

LFTRs are a remerging reactor, they're derived from MSR designs; and are described as "heterogeneous" by the World Nuclear Assoc. (WNA,2018). LFTRs utilise the decay process of ^{232}Th,

$$^{232}_{90}\text{Th} + {}^{1}_{0}\text{n} = {}^{233}_{90}\text{Th} = {}^{233}_{90}\text{U} \xrightarrow{\beta^-} {}^{233}_{91}\text{Pa} \xrightarrow{\beta^-} {}^{233}_{92}\text{U} \text{ (fuel for fission reactions)}$$

(Ipfs.io, 2017). When the decay process of ^{232}Th and ^{235}U are contrasted, both generate fission, but no gamma waves are observed in the decay of ^{232}Th. The lack of a photon makes the reactor less hazardous (DOE, n.d.) and more cost-effective; due to the lack of investment in larger concrete barriers for the reactor.

LFTRs hold three general augmentations over PWRs; increased safety, feasibility and lowered costs.

This investigation will examine the Flibe LFTR model. (fig2)

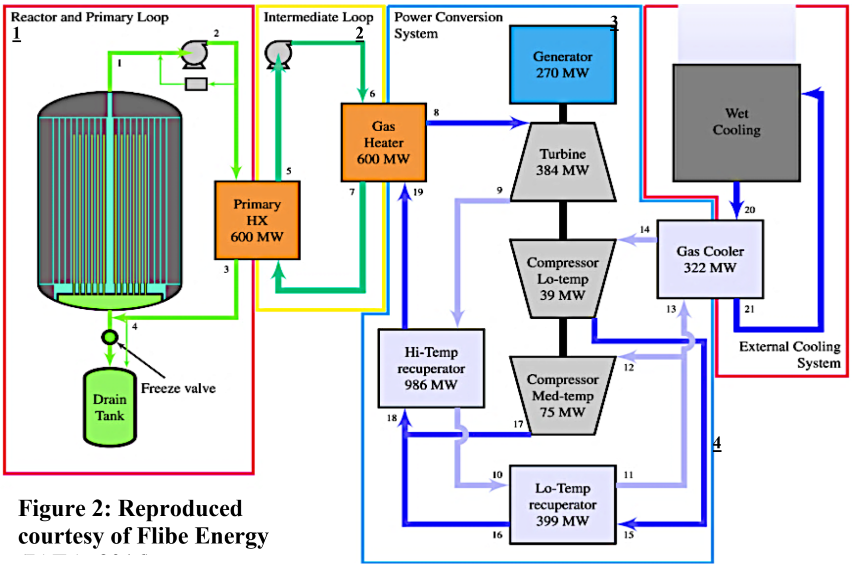


Figure 2: Reproduced courtesy of Flibe Energy

LFTRs have passive safety systems; if a failure occurs the reactor will autonomously deactivate itself. The freeze valve located in Area 1 (fig.2) makes the system passive, if the reactor stopped the valve would melt and the drain tank would fill(WNA,2018).

The Three Mile Island failure was a partial meltdown (ucalgary.ca, 2018), LFTRs materials are molten. The Chernobyl failure was a system flaw that caused a steam explosion, no water is used in LFTRs (WNA, 2019). The Fukushima reactor didn't have a passive safety system. Ultimately LFTRs won't cause another Three Mile Island, Chernobyl or Fukushima.

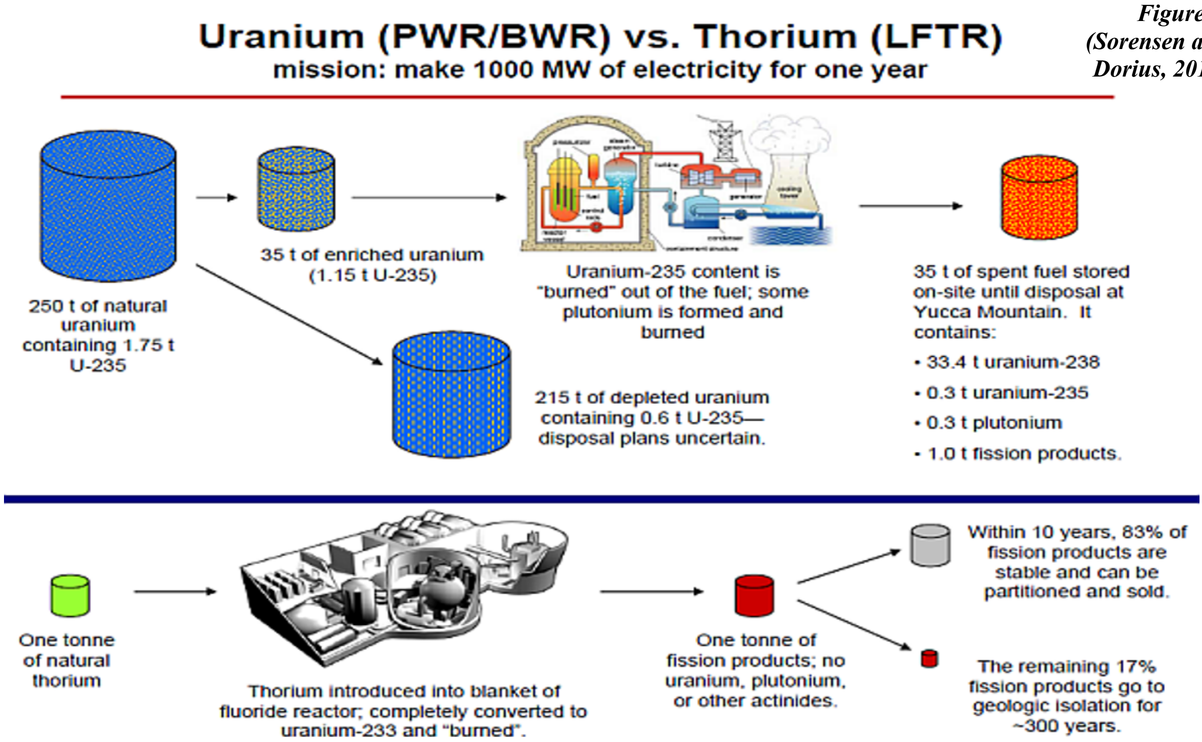
A feasible project is defined as being achievable and reasonable (Cambridge, 2019). SMRs modularity refers to the reactors scalability and facilitated construction processes. Unlike PWRs SMRs can be built offsite, with minimal onsite work necessary (Energy.gov, 2019). LFTR plant sizes are determined by regulatory costs rather than technical constraints; this is due to the ability designers have to adjust the plant size/design. LFTRs don't require water so they can provide energy for remote communities anywhere (WNA, 2019). LFTRs are reasonably achievable.

SMRs will have a lower capital investment that the current reactors; due to no fuel enrichment process, less land requirements and construction costs (Energy.gov, 2019). The fuel enrichment costs aren't applicable. SMRs require less land than PWRs due to their size, the land purchasing/clearing costs diminish. The decreased size of LFTRs, decreases the reactors construction costs. I.e. LFTRS don't require light water sources/high-pressure tanks. Thorium is also abundant=cost-effective ("Thorium in Australia – Parliament of Australia", 2008).

Why aren't there Thorium mines?

Thorium is over 3 times more abundant than uranium (World Nuclear Association, 2017). Thorium's is currently a by-product of other mining expeditions and is disposed as a waste (Ferris-haggarty.com, 2016). Fig.3 contrasts Thorium and Uranium. The illustration highlights the enrichment process associated with uranium fuelled reactors (PWRs) effect.

Figure 3. (Sorensen and Dorius, 2011)



Why aren't LFTR's popular?

The termination of thorium research was due to political factors. WWII had finished and the race for nuclear weapons began. Uranium reactors generate by-products of ^{239}Plutonium, with <10kgs of the fissile isotope a bomb was feasible (WNA, 2018). The LFTR experiment hadn't produced any materials adequate for quick militarisation; consequently, LFTR research stopped.

Model comparisons:

	Nuclear Reactors ~ PWR	**Small Modular Reactors ~ LFTR (Flibe)**
Fuel (+its natural abundance%) (AUSGov, 2019)	Enriched Uranium=>^{235}U <1%Natural U=^{235}U	Natural Thorium=>^{232}Th 99%>Natural Th=^{232}Th
Safety system	Active	Passive
Neutron moderator/ Coolant	Both=Light water	Graphite/Molten Fluoride
Total CO_2 emission (appendix 1) (Co2 emission is measured from the transportation requirements of the reactors.)	Moderate-due to the demanding process associated with the fuel and creation of the reactor's sections.	Minimal-due to the lack of high-risk processes associated with the reactor's components.
Regulation& requirements.	Land req.=approx. 20.5km^2 (Zyga, 2011) Federal law in Australia bans nuclear power (Australian Nuclear Association, 2018).	Land required=unknown but will be <20.5km^2 due to the decrease in the reactors size. Bn applies; possibly overturned in the investigation (Parliament of Australia, 2019).
Approximately when will...	The waste will degrade in approx. 24,000 years (Visionofearth.org, 2010).	All the waste will degrade <300 years.
Easy transferable? Modular?	Not modular. The reactors parts must be built offsite, reactor must be built onsite. No exceptions.	Very modular. Construction can be onsite or offsite.
Potential for militarisation?	Yes, previously the by-products (^{239}Pu) created were militarised.	Technically, the by-products can be militarised, but aren't due to the inefficient & over complex process (Touran, 2014).
Australian Government interest?	Yes previously, the Australian gov. (+its independent state gov.) completed inquiries into nuclear reactors; i.e. French Island VIC 1967 and Jervis Bay NSW 1969-1971.	Yes currently, the Australian gov. has petitioned for a parliament investigation into the implementation of SMR's in Australia. LFTR are SMR's, their potential will most likely be investigated. (Parliament of Australia, 2019). As shown in Appendix 6, The Australian Nuclear Association described SMRs as "well suited" for Australia.
Reputable individuals/ associations supporting…	Global interest, with 292 PWRs operating (World Nuclear Association, 2018).	Alvin Weinberg (2004); Ontario Power Generation (2019): (Malcolm Turnbull (<2006) etc. (Refer->Appendix 5).

Quality of Evidence:

Identified limitation:	*Impact:*

1. Lack of reliable sources about LFTR's.	LFTRs currently have a lack of sources. This impact was foreseen and surprisingly impacted the investigation marginally.
2. Authenticity of secondary and third level sources utilised.	Prominently international organisations, university, and government endorsed websites were used; validating the authenticity of the information used. Some third level sources were utilised, due to limitation#1. It's recommended that at some point a third party confirm that the information utilised is true.

Improvements to the investigation:

Identified improvement:	*Benefit:*
Research into potential disasters with LFTR's	Due to the lack of LFTR information it cannot be affirmed that there are no dangerous aspects within the reactors. To further assert the safety of LFTRs further research should be completed. The results established would assist in the conclusion of LFTR's feasibility.
More research from current Physicists surrounding LFTR's.	Utilising research that's being published in 2019, will extend and improve the investigations scope of information. Using the latest in technological advancements is favourable.

Extensions to the investigation:

Identified extension:	*Benefit:*
Including information from the AUS. Energy Committee's inquiry.	In September 2019 the Australian Energy and Emissions Reduction committee will begin an inquiry into nuclear energy for Australia (Parliament of Australia, 2019). This document will hold government endorsed and approved information. Utilising the reports would further justify any decision concluded through this investigation.
Watch (through the free livestream) the "International Conference on… Nuclear Power October 2019, Vienna, Austria"	The IAEA communicates the advancements within Nuclear technology. In October 2019 they will have a conference, to discuss the potential nuclear technology. (Iaea, 2019) Research presented at the conference would greatly extend and affirm/refute the conclusion presented about SMR's and LFTR's viability.

Evaluation of the claim & conclusion:

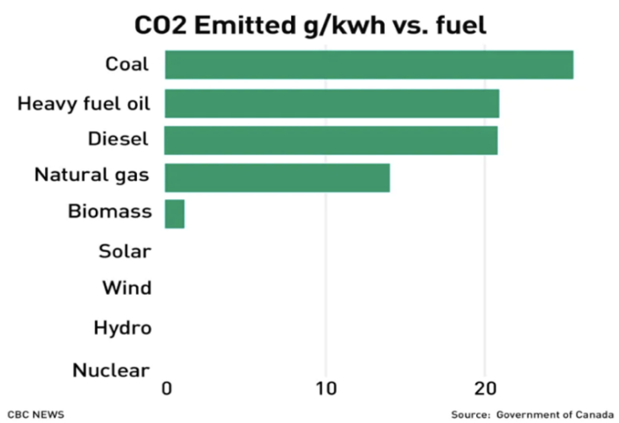
TV's, telephones and technology in general has significantly advanced since the 1960s, but nuclear technology hasn't. This investigation has contrasted the PWR and LFTR; to confirm whether LFTRs can replace the popular use of PWRs. The evidence gathered has proven 5 key differences between the reactors; LFTRs have proven to utilise a more abundant and efficient fuel source, require less investment, provide more safety, versatility and feasibility than PWRs. When the evidence gathered is applied to the claim, the claim is refuted as the current technology utilised (PWRs) aren't as effective/safe as other reactors (LFTRs). Alvin Weinberg was a scientist whom worked to create both the PWR and LFTR; Weinberg, one of the most reputable nuclear physicists was a proponent of LFTRs. Consequently, this investigation concludes that the production of LFTRs would greatly benefit humanity; the research question is satisfied.

Word count:1997

Bibliography:

1. World Nuclear Association. (2019). Nuclear Power in the World Today. [online] Available at: https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx [Accessed Aug. 2019].
2. US EPA. (2019). Energy and the Environment | US EPA. [online] Available at: https://www.epa.gov/energy [Accessed Aug. 2019].
3. ucsusa.org. (2017). Why Does CO2 get Most of the Attention When There are so Many Other Heat-Trapping Gases?. [online] Available at: https://www.ucsusa.org/global-warming/science-and-impacts/science/CO2-and-global-warming-faq.html [Accessed Aug. 2019].
4. World Nuclear Association. (2019). Safety of Nuclear Power Reactors. [online] Available at: https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx [Accessed Aug. 2019].
5. World Nuclear Association. (2018). The Nuclear Debate. [online] Available at: https://www.world-nuclear.org/information-library/current-and-future-generation/the-nuclear-debate.aspx [Accessed Aug. 2019].
6. Government of Canada (2019). What you need to know about small modular reactors | CBC News. [online] Available at: https://www.cbc.ca/news/technology/small-modular-reactors-nuclear-smr-1.5187469 [Accessed Aug. 2019].
7. Iaea. (2019). Home: International Conference on Climate Change and the Role of Nuclear Power | IAEA. [online] Available at: https://www.iaea.org/atoms4climate [Accessed Aug. 2019].
8. World Nuclear Association. (2018). Nuclear Power Reactors. [online] Available at: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors.aspx [Accessed Aug. 2019].
9. Australian Nuclear and U Sites. (n.d.). Australian Map of Nuclear and Uranium Sites | Map of Australia. [online] Available at: https://australianmap.net/?doing_wp_cron=1566523636.4047501087188720703125 [Accessed Aug. 2019].
10. Parliament of Australia (2019). Inquiry into the prerequisites for nuclear energy in Australia – Parliament of Australia. [online] Aph.gov.au. Available at: https://www.aph.gov.au/nuclearpower [Accessed Aug. 2019].
11. WNA. (2018). Physics of Uranium and Nuclear Energy. Retrieved August 2019, from https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/physics-of-nuclear-energy.aspx#ECSArticleLink1
12. AUSGov. (2019). Uranium and Thorium. Retrieved August 2019, from https://www.ga.gov.au/education/classroom-resources/minerals-energy/australian-energy-facts/uranium-and-thorium
13. DOE. Characteristics of Alpha, Beta and Gamma Radiation. Published by the U.S Department of Energy (DOE), Office of Science. Retrieved August 2019, from https://orise.orau.gov/reacts/guide/basics/radiation-characteristics.html
14. NRC. (2019). NRC: Uranium Enrichment. Retrieved August 2019, from https://www.nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html
15. IN2P3. IN2P3 French Institute of Nuclear Physics and Particle Physics. Radioactivity: PWR Reactors. Retrieved August 2019, from http://www.radioactivity.eu.com/site/pages/PWR_Reactors.htm
16. Ucalgary.ca. (2018). Three Mile Island nuclear accident - Energy Education. Published through the University of Calgary. Retrieved August 2019, from https://energyeducation.ca/encyclopedia/Three_Mile_Island_nuclear_accident
17. WNA (2019). Small Nuclear Power Reactors. [online] Available at: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx [Accessed Aug. 2019].

18. Zyga, L. (2011). Why nuclear power will never supply the world's energy needs. [online] Phys.org. Available at: https://phys.org/news/2011-05-nuclear-power-world-energy.html [Accessed Aug. 2019].
19. Australian Nuclear Association (2018). Nuclear Power – some facts – Australian Nuclear Association. [online] Nuclearaustralia.org.au. Available at: http://www.nuclearaustralia.org.au/nuclear-power-some-facts/#_ftn2 [Accessed Aug. 2019].
20. WNA (2018). Plutonium. [online] Available at: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/plutonium.aspx [Accessed Aug. 2019].
21. WNA (2018). Molten Salt Reactors. [online] https://www.world-nuclear.org. Available at: https://www.world-nuclear.org/information-library/current-and-future-generation/molten-salt-reactors.aspx [Accessed 2019].
22. WNA (2019). Chernobyl Accident 1986. [online] Available at: https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident.aspx [Accessed Aug. 2019].
23. Touran, N. (2014). Thorium myths. [online] Whatisnuclear.com. Available at: https://whatisnuclear.com/thorium-myths.html [Accessed Aug. 2019].
24. Ipfs.io. (2017). Thorium fuel cycle. [online] Available at: https://ipfs.io/ipfs/QmXoypizjW3WknFiJnKLwHCnL72vedxjQkDDP1mXWo6uco/wiki/Thorium_fuel_cycle.html [Accessed Aug. 2019].
25. Roberto, J. and Nestor, M. (2014). Biographical Memoir of Alvin M. Weinberg. [online] Nasonline.org. Available at: http://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/weinberg-alvin.pdf [Accessed Aug. 2019].
26. IAEA (2016). [online] Aris.iaea.org. Available at: https://aris.iaea.org/PDF/LFTR.pdf [Accessed Aug. 2019].
27. Energy.gov. (2019). Benefits of Small Modular Reactors (SMRs). [online] Available at: https://www.energy.gov/ne/benefits-small-modular-reactors-smrs [Accessed Aug. 2019].
28. Sorensen, K. and Dorius, K. (2011). Introduction to Flibe Energy. [online] Thoriumenergyalliance.com. Available at: http://www.thoriumenergyalliance.com/downloads/TEAC3%20presentations/TEAC3_Sorensen_Kirk.pdf [Accessed Aug. 2019].
29. Ferris-haggarty.com. (2016). National Security - Rare Earth Elements & It's Uses Amazing & Life Altering is a UNDERSTATEMENT!. [online] Available at: https://www.ferris-haggarty.com/rare-earth-elements---ree [Accessed Aug. 2019].
30. Thorium in Australia – Parliament of Australia. (2008). Retrieved August 2019, from https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/RP0708/08rp11
31. Visionofearth.org. (2010). Does nuclear waste last millions of years? – Vision of Earth. [online] Available at: https://www.visionofearth.org/news/does-nuclear-waste-last-millions-of-years/ [Accessed Aug. 2019].



Appendix 1:

(Government of Canada, 2019)

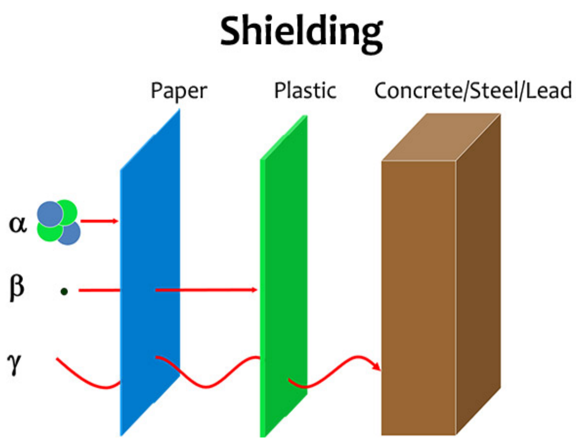
This statistic was released by the Government of Canada. It expresses how the fission process, doesn't create any CO_2. While highlighting how much CO_2 other fossil fuels produce.

Appendix 2:

The following explains how much of the energy utilised globally in 2018 was obtained from PWR.

1. 11% worlds energy = sourced from nuclear reactors
2. 292 of the 448 nuclear reactors are pressured water reactors (PWR'S)
3. 65.1% nuclear energy = sourced from pressurised water reactors
4. 65% of 11 = 7.15%
5. ∴ 7% of the global energy used is sustained from PWR's

(World Nuclear Association, 2018)



Appendix 3:

(DOE, n.d.)

This statistic was gathered by the U.S Department of Energy (DOE), Office of Science. The diagram explains how gamma rays are the most difficult radioactive emission to contain. The diagram highlights how potentially dangerous these waves may be (particularly when they're of improperly contained).

Appendix 4:

The following explains how the natural Uranium mined globally in 2018 would have utilised.

1. Total Uranium mined globally in 2018 = 53,498 tonnes *(World Nuclear Association, 2019)*
2. Naturally fissile Uranium → 0.7% of 53,498T = 3,745T
3. Amount of Uranium requiring enrichment → 53,498T - 3,745T = 49,753T
4. ∴ Approx. 50,000 Tonnes of Uranium mined in 2018 requires the enrichment process.

Appendix 5:

The following is the referencing for all the individuals and associations mentioned in the model comparison table on page 6. Appendix 5.1 is the referencing for the multiple Physicists referenced. The graphs below don't reflect the increasing number of individuals and organisations beginning to support both SMRs and LFTRs; the true number of supporters can be seen through a google investigation (search). Unfortunately, that information wouldn't fit in the tables below.

Individual/ Association	Referencing and relevant information (awards/education):
Ontario Power Generation	OPG (2019). News>Small Modular Reactor (SMR) Update [Accessed Aug. 2019] Available at: https://www.opg.com/news/small-modular-reactor-smr-update/
Malcolm Turnball	"Cheaper than new coal and far cheaper than nuclear." https://www.abc.net.au/news/2019-08-07/small-modular-reactors-nuclear-explained/11386856
India (2016)	http://www.thoriumenergyworld.com/news/india-aims-to-build-worlds-first-thorium-ads
Russia (2016)	http://www.thoriumenergyworld.com/news/putin-has-thorium-plans-and-engages-russias-vast-nuclear-establishment
Bjorn Stigson (2016)	Former President of the World Business Council for Sustainable Development http://www.thoriumenergyworld.com/news/sustainability-and-the-role-of-thorium
Chinese thorium MSR project (2010>)	https://www.nextbigfuture.com/2018/08/china-has-multi-billion-projects-developing-liquid-and-solid-fuel-molten-salt-reactors.html
Alvin Weinberg Foundation (2011)	http://powerbase.info/index.php/Alvin_Weinberg_Foundation
ThorCon	http://thorconpower.com
Flibe	https://flibe-energy.com

Appendix 5.1

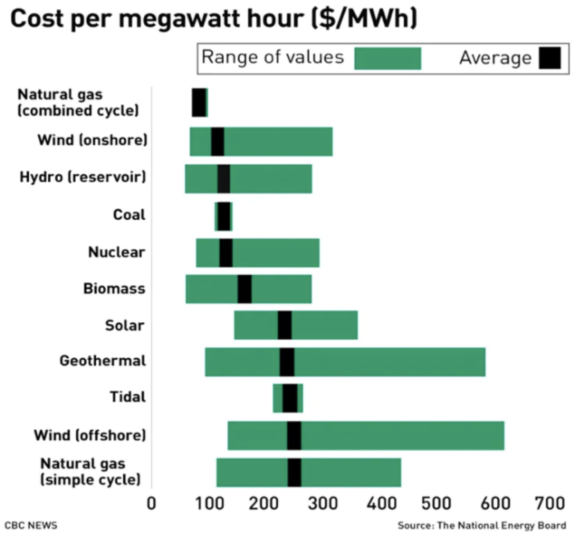
Name:	Relevant information (awards/education) and referencing:
Steven Cowley	*Awards*: Glazebrook Medal of the Institute of Physics; Harkness Fellowship; Knight Bachelor (2018); Richard Glazebrook Medal and Prize (2012) https://www.ted.com/talks/steven_cowley_fusion_is_energy_s_future
Kirk Sorensen	*Education:* B.S. in Aerospace Engineering from Utah State University in 1998, his M.S. in Aerospace Engineering from the Georgia Institute of Technology in 1999, and he is currently studying Nuclear Engineering at the University of Tennessee-Knoxville. https://www.youtube.com/watch?v=0BybPPIMuQQ

Appendix 6:

The following is a quote from the Australian Nuclear Association, with key points underlined.

"Nuclear plant scale: …A new generation of Small Modular Reactors (SMRs) promise factory-built modules rated from 10 MWe to 250 MWe and designed to load-follow. They would be well suited for incremental additions to Australia's National Electricity Market as fossil fuelled plant is retired."

- (Australian Nuclear Association, 2018)



Appendix 7:

(Government of Canada, 2019)

This statistic was released by the Government of Canada. It expresses the cost per megawatt hour of the 11 most utilised energy generators. From the figure it can be interpreted that the cost per megawatt hour for nuclear and fossil fuel-based energy production is equal. This figure would have been made with data from largescale nuclear reactors so if SMR's energy production was analysed it would most likely cost less than the cost of fossil fuel energy.