

Leveraging Thorium to address growing energy needs worldwide in a climate responsible manner.

- **Staying below 1.5°C in 2100 will require cuts in GHG emissions of 45 percent below 2010 levels by 2030 and to net zero by 2050.**

Ref. IPCC Special Report on Global Warming of 1.5°C

- **We thus have only 10 years to realise deep emission cuts and 30 years to reach zero emission while addressing development aspirations of much of the world. Actions have to start now leveraging available/rapidly deployable technologies that can achieve the goals.**

➤ **Actions:**

- **Countries with high quality of life (green dot countries in fig. below)**

- **Reduce electricity consumption**
- **Decarbonise electricity generation**

} **No impact on HDI.**

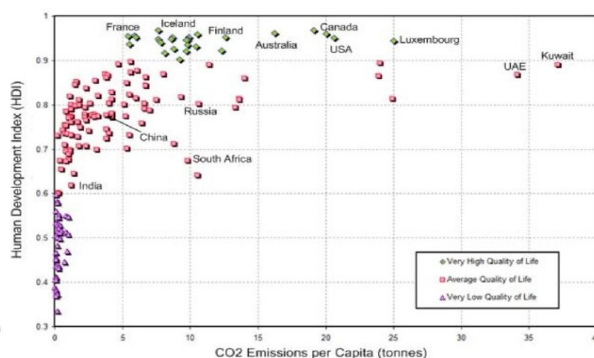
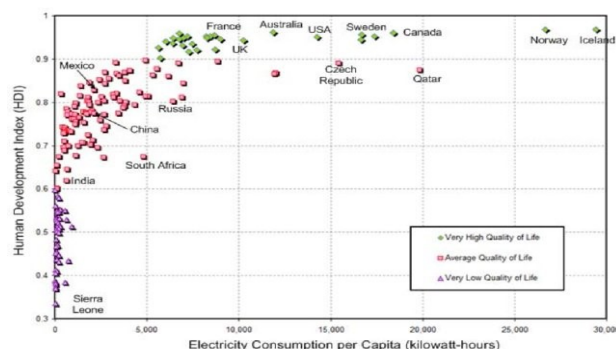
- **Countries with average quality of life (pink dot countries in fig. below)**

- **Increase non-fossil electricity consumption**
- **Decarbonise electricity generation**

} **+ve impact on HDI. Much larger market, most of them being emerging economies.**

- **Countries with very low quality of life (purple dot countries in fig. below)**

- **Subsidise energy access including through international action**



- **While renewable energy is an important deployment option, nuclear power can make a vital contribution to meeting zero emission target while delivering the increasingly large quantities of base load electricity needed for global economic development. Without nuclear contribution, the cost of achieving deep decarbonization targets increases significantly.**

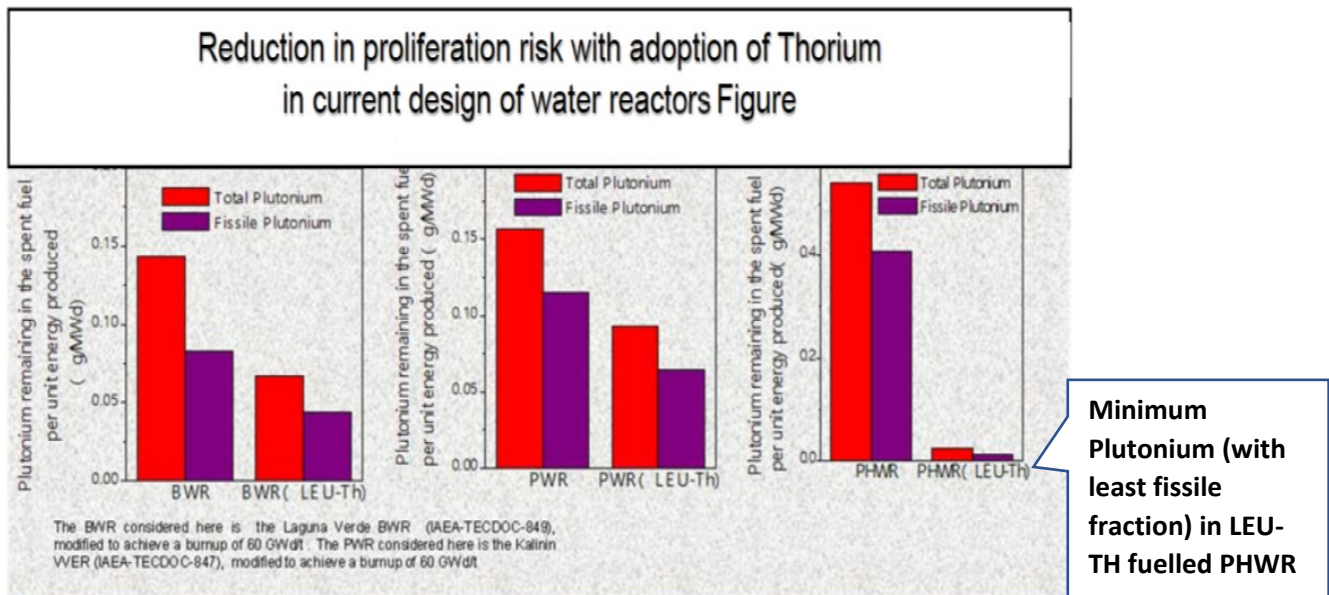
Ref. 1. The Future of Nuclear Energy in a Carbon-Constrained World. An Interdisciplinary MIT Study 2018
2. IAEA report on "Climate Change and Nuclear Power 2018"

- **For maximum climate favorable impact, we need to focus on pink dot countries. In reality however, of around 50 new nuclear power reactors that are under construction in fifteen countries post Fukushima, only three (Bangladesh, Belarus and UAE) among them are a new entrant to the use of nuclear power. Clearly, there are barriers to deployment of nuclear power that need to be understood and addressed.**
- **What are these barriers?**
 - **Nuclear proliferation** – This to my mind is the strongest (mostly unstated) barrier particularly in regions with perceived security deficit
 - **Safety** – People are concerned in view of accidents, with large public impact, that have taken place
 - **Used fuel management** – Long term storage of used nuclear fuel is perceived as an open-ended issue
 - **Financial** – We need solutions that are cost competitive with minimum financial risks

Clearly, we need solutions that can address these barriers and are ready for deployment to penetrate the potential market that exists in pink dot countries.

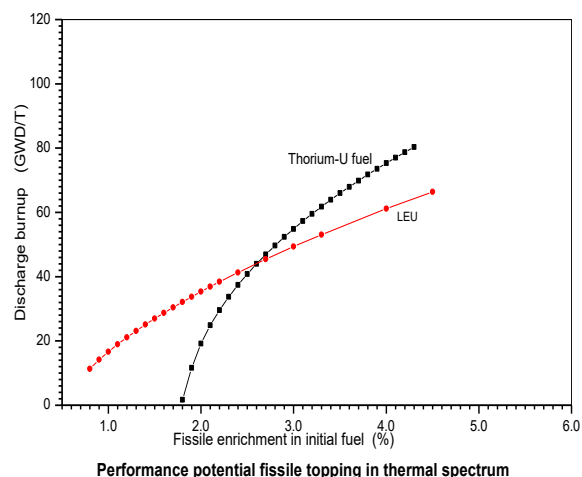
- **Pressurised Heavy Water Reactors (PHWRs) - powered with CCTE designed LEU-Th ANEEL (Advanced Nuclear Energy for Enriched Life) fuel would appear most promising for following reasons.**
 - **Nuclear proliferation** – LEU-TH ANEEL fuel leads to high degree of proliferation resistance, - through deep burning of plutonium (best result in PHWR – pl. see figure below) and hard gamma emitting U-232 daughter

products. Much higher confidence related to nuclear non-proliferation during long term storage of used fuel.



• **Safety –**

- **PHWRs have some unique inherent characteristics that strengthen safety such as availability of cool moderator as heat sink within the reactor core, low excess reactivity because of availability of on power refuelling, reactivity elements being located in low pressure environment precluding ejection possibility, double containment system with passive energy management etc.**
- **Thorium oxide, because of its higher thermal conductivity, operates at a lower temperature and because of its higher melting temperature offers a further margin from fuel melting as compared to uranium oxide.**
- **Excellent operation record of PHWRs. Unit one of Kaiga Generating Station holds the world record of longest continuous operating run of 962 days. The continuous operation of more than a year has so far been achieved 33 times by various reactors operated by NPCIL India.**



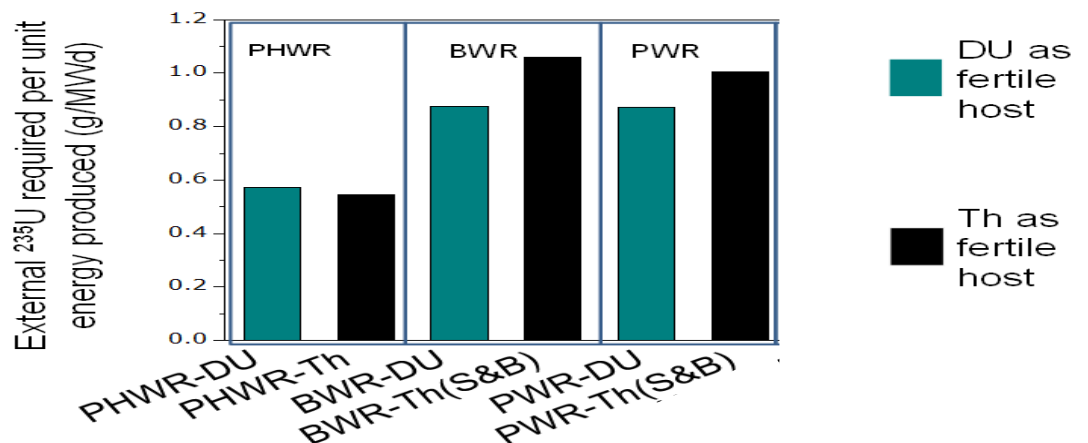
- **Used fuel management –**

- At high burn up levels (which was not feasible in earlier phase of nuclear power development), LEU-TH ANEEL fuel contributes to reduction in fuelling needs. (Pl. see figure above).
- Higher burn-up with LEU-TH ANEEL fuel in PHWRs reduces the used fuel quantity to nearly one eighth with corresponding reduction in fuel management cost.
- Thoria matrix in LEU-TH ANEEL fuel is relatively inert providing greater confidence on long term stability of used fuel.

- **Financial –**

- PHWR/CANDU systems are operational in seven countries. 220MWe PHWRs (15 units operating in India) and CANDU 300 (450 MWe unit designed by Canada) are among the smallest nuclear power units. A much larger number of bigger PHWR units are in operation (30 in six countries) or under construction (16 in India).
- These units are amenable for construction by countries with light/medium manufacturing infrastructure. Under Indian conditions, the 220 MWe units have shown lower per MWe capital cost even when compared to the larger (1000 MWe +) LWRs supplied from industrially advanced countries.
- Heavy water reactors have best neutron economy and maximise advantage that thorium offers.

Heavy water reactors offer better economy in use of fissile material over light water reactors, with thorium as the fertile host



➤ **Strategy going forward**

- **Leverage a readily available PHWR/CANDU design with proven safety and manufacturing infrastructure**

- **LEU-TH ANEEL fuel with external configuration identical with existing fuel for these reactors has been designed by CCTE meeting the performance criteria. Irradiation qualification is being arranged at the US Department of Energy's Idaho National Laboratory.**
- **While there are a number of other nuclear reactor configurations under development, looking at the urgency for deployment of solution as mentioned in the beginning, this is really a low hanging fruit that should be leveraged for the global good.**