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RESEARCH ARTICLE

Towards sustainable, secure and safe energy: A future for thorium power

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Abstract: Thorium (Th) is three to four times more abundant than Uranium (U) in nature and distributed evenly in most developing countries in the World. Th can be mined with relatively cheap and environment friendly mining methods from high grade alluvial deposits. Th extraction is relatively straightforward and inexpensive. Th has better radiation stability and longer fuel cycle. Th has a higher energy density and fuel economy in the reactors. One ton of mined Th produces as much energy as 200 tons of mined U, or 3.5 million tons of coal. World's global energy needs for one year can be supplied by approximately burning 6000 tons of Th. Since Th is an abundant and sustainable source of energy for the future, developing countries cannot afford to ignore. Molten salt and accelerator driven reactors have been developed for Th-fuel. Turkey has the sixth biggest Th resources in the world and must declare Th as part of countries national power policy like China and India.

Keywords: Th-fuel, nuclear fuels, sustainable source of energy

1 Forgotten treasure

1.1 Sustainability of energy sources

Nothing is sustainable in the long run, not our sun and not life on this planet. Sustainability only makes sense as a relative concept with respect to the human timescale. The definition of sustainability may become complex when adding environmental, economic, or social considerations. For our purpose, a sustainable energy source could be defined as a source of energy with reasonably manageable impact on the environment, and one that will last long enough for an innovative technology to provide a replacement.[1]

Primary energy source in the world was wood in between 1850 and 1900; coal between 1900 and 1950; oil between 1950 and 2000; natural gas between 2000 and 2050 and nuclear and/or renewable (solar/ wind) energy will be after 2050.[2] Energy sources successively substituted and dramatically changed today. There is a significant increase in nuclear (after 1965), solar and wind (after 1995) energy productions; but U-fueled nuclear energy did not live up to expectations and renewable energies have experienced in conquering a substantial part of the world market due to newly discovered reserves of coal, gas and oil have extended the dominance of fossil fuels. Present solar energy photovoltaics (PVs) may not yet be sustainable due to constraints on the availability on rare materials (*i.e.* In, Te, Ge and Ru).[1]

Life expectancies of fossil fuels are 50-100 years. If consumption continues to increase, the end of fossil fuels will occur sooner. Replacing fossil fuels is a major challenge for society. They create global warming, air pollution, and should be used in manufacture of plastics, rubber, paints, glues, asphalts, drugs, fertilizers, cosmetics, detergents etc. rather than burning for energy. In 2015, fossil fuels still represented 86% of the primary energy consumption.[3] Growth in energy demand is expected to be primarily driven by the developing economies. In 20-25 years from now, developing countries will be dominant players in the energy market. Sustainable, secure and safe solution to the energy problem can only be come from intensive and systematic R& D in nuclear fission and renewable energies.

Nuclear resources are abundant and energy intensive. For example, 1 GW can be sustained for one year by using only 1 t of Th, compared with 3-4 million tons of coal or 60 km^2 of solar cells at the latitudes of Paris.[1] Nuclear fission energy can ensure base load electricity production, it produces neither greenhouse gases nor air pollution, and it could be made sustainable. If it were not for accidents, waste management, and proliferation issues, there would be no reason to want to stop nuclear

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power plants. It is clear that the present way of exploiting nuclear energy was selected for other reasons: The U-fuel cycle was chosen to produce plutonium (Pu) for nuclear bombs; Pressurized Water Reactors (PWRs) were invented to fit on a submarine.

1.2 Thorium: A sustainable source of energy

Th is the Earth's greatest source of stored energy. Created billions of years ago in the final moments of a dying star, it holds enough energy in the structure of its nucleus to safely power human society for millions of years. Prominent physicists and Nobel Prize Laureate Prof. Carlo Rubbia defends Th-fuel in fast neutron Accelerator Driven Systems (ADS) to make a major contribution to the solution of energy problem. Also Th will help the nuclear waste management problem. Table 1 shows the first highest 10 countries with Th resources in the world. World total Th resource is 6.3×10^6 tons. It is estimated that the Earth's crust contains 1.2×10^{14} tons of Th, which is about the same amount as Pb.

Table 1. Estimated world Th resources in tons[4]

Country	Reserve	Country	Reserve
India	846,000	Turkey	380,000
Brazil	632,000	Venezuela	300,000
Australia	595,000	Canada	172,000
USA	595,000	Russia	155,000
Egypt	380,000	S. Africa	148,000

Th resources are broadly distributed on the Earth, which has obvious geopolitical advantages. ^{232}Th is more abundant than U, it is 100% usable vs. less than a percent for U and enrichment is not required.

Th is not fissionable, so one must produce the ^{233}U isotope from Th to obtain fission. Breeding of ^{233}U uses essentially all the Th. In PWRs, it is only ^{235}U, present at a level of 0.7% in natural U, which is used. As a result, Th represents a greater energy supply by a factor of 140, which, when combined with the higher Th abundance, corresponds to an overall factor of 500 times more potential Th resources compared with U.[1] Assuming 2.5 TW present world electric power consumption, the 6.3 million tons of Th reserves can provide energy to whole planet for 2500 years.

1.2.1 Benefits of thorium?

Known and experimented since the 1950s, Th has the following advantages:

1.2.1.1 Waste

Waste produced by Th nuclear plants is much reduced and have a much shorter lifetime than its ^{235}U counterpart. There is no need to store them for periods extending over thousands of generations.

1.2.1.2 Security

In this field, Th is a class apart. The many safety devices are of passive type and work on the laws of physics without any technical or human intervention. Th systems function at ambient pressure, and the rubbiatron; *i.e.*, shuts down by itself in case of system failure or earthquake. This is due to its characteristic subcritical reactor. The waste heat is then continuously removed by natural convection, without further consequences.

1.2.1.3 Efficiency

Almost all of the Th can be converted into thermal energy (against only 1/200 in the case of U). This diminishes the amount of waste and lost energy.

1.2.1.4 Abundance

Th is nearly 4 times more common in the crust than U (9,6 mg/kg against 2,7 for U). Considering its efficiency, it means that the Th can ensure a future energy production 700 times longer than U.

1.2.1.5 Nuclear Proliferation

The Th and its by-products have excellent resistance characteristics to nuclear pro liferation. The militarization of this sector requires too complex processes to be useful and Th produces only trace amounts, in practice unusable, of Pu. This is an obvious advantage.

1.2.1.6 Flexibility

It is very possible to build Th plants that can easily and quickly adapt to irregular production of renewable energy, which the U systems do not allow.

1.2.1.7 Bonus

Additionally, some Th systems allow for the transformation, with energy production, of the U-generated highly radioactive waste into manageable waste with a shorter lifespan. This is probably the best (only) way to solve the problem of nuclear waste created during almost 40 years. According to the International Thorium Energy Committee (iThEC), it is time to correct the wrong choice due to the cold war and quickly convince civil society that "nuclear power" does not mean "^{235}U" To quickly build Th "waste-eaters" plants before we lose control over nuclear waste and set up additional energy production systems complementary to renewable energies. We are about to enter a new nuclear era!

1.3 Why thorium?

Using Th fission instead of U reduces the toxicity and longevity of nuclear waste. Th can be mixed with radioactive waste from current U-fuelled reactors inside new Th reactors to reduce the existing stockpile of nuclear waste. The waste products from a Th-fuelled reactor do not include weapons-grade materials in the amounts required for producing a bomb. Th lends itself to its use in a subcritical reactor, which operates far from criticality and is inherently safer. The decay heat which

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needs to be cooled after a nuclear reactor is shut-down, can be removed passively in a Th ADS reactor. Th can be extracted from many parts of the globe, in less politically sensitive regions and in greater quantities than U.

Flibe Energy in the USA is trying to develop a Th based molten salt reactor (TMSR). Prof. Rubbia has been working on an accelerator driven reactor. According to Kirk Sorenson from Flibe Energy, the LFTR has the least impact on its surroundings compared to any other energy system. It would be totally safe, look like a normal small industry facility with extra protection.

Following the success of the previous Th conferences, *i.e.* ThEC10 (UK), ThEC11 (USA) and ThEC12 (China), ThEC13 (Switzerland) and ThEC15 (India), iThEC was created in Geneva on September 2012 and brought together regional actors in the development of Th energy systems in order to obtain an overview of all the activities and promote cooperation. iThEC is a Swiss-based association of aiming at developing Th energy systems, with a focus on ADSs, Prof. Rubbia's brainchild, with the capacity of destroying nuclear waste.

2 Thorium resources

2.1 Natural properties

Th is naturally-occurring slightly radio-active and dense actinide metal (*i.e.* less radio toxic). Th exists in nature almost entirely as stable ^{232}Th isotope and itself cannot sustain a nuclear chain reaction. Th is a lustrous silvery-white metal. It is fertile material, accept a neutron and transmute into fissile ^{233}U and decays until to stable ^{208}Pb. Natural Th is isotopically pure, found mostly in monazite ores, but also in thorite ($ThSiO_4$) and in thorianite (ThO_2+UO_2), and is relatively cheap as it is often a by-product of rare earth elements (REEs) containing monazite [(REE-Th) PO_4] or bastnasite [(REE-Th)$FCO_3{}^2$] minerals. Monazite contains up to 20% ThO_2 and 16% UO_2 while bastnasite contains 0.3% ThO_2. Radio active Th and U containing REEs may be phosphate, silicate and carbonate containing minerals. Th is found in placer deposits, beach sands and is also a component of the World's biggest REE Bayan Obo deposit in China. World's yearly monazite production is between 5000-6500 tons. Th from monazite deposits can be mined with low-cost and environment friendly mining methods; because, it exists in high concentrations and grades at the surface or in beach sands. The ore/sand can be skimmed off the surface by dredge mining. Monazite mining is more economical due to presence of Th as a by-product in the REE ore. ThO_2 is liberated from monazite by gravity, magnetic and electrostatic concentration methods, using minimum dangerous concentrated acids. Whereas U is mined by expensive underground mining, or open pit mining and insitu acid leaching methods. Bastnasite is a fluoro-carbonate mineral with a REO content of approximately 70% (Ce, La, Pr and Nd). Basnasite is the primary source of light REOs and accounts for 80% of the overall amount of REO in the World. In the last 50 years, bastnasite replaced monazite as a chief mineral source of REEs. Bastnasite has been extracted on a large scale only in Mountain Pass-USA and Bayan Obo-China, which supplies 45% of World demand alone. In the production, expensive underground mining methods are used. Bastnasite processing depends on fine grinding; gravity, magnetic and flotation separations; calcinations; HCl leaching and solvent extraction steps. Kaya (2013) and Kaya & Kursunoglu (2014a and b) give Th and U ores formulas, densities, magnetic properties, chemical contents, mining and concentration methods.

2.2 Th Basics as a nuclear fuel

Th is plentiful in nature, generally well distributed throughout the earth crust and virtually inexhaustible nuclear fuel. Th is one of only a few substances that act as a thermal breeder. It is impossible to make nuclear weapons/bombs from Th by terrorists (*i.e.* peaceful). Therefore, nuclear power without proliferation has obvious political appeal for many governments in the World. Th can be also used as a "fertile matrix" for fuels containing Pu and Am. Th has a high heat capacity (*i.e.* smaller reactors can be made). It does not require costly mineral processing methods (*i.e.* less expensive). Th is extraordinally efficient nuclear fuel (*i.e.* allows longer fuel burnups in the reactors). Th produces more neutrons per collision; thus, twenty-forty times more energy is generated, less fuel is consumed and forty-seven times less radioactive wastes are left behind to take care. Th fuel is completely used up in the reactor. Th reactor wastes need to be stored for only few hundred years not for a few thousand like U reactors. Th reactors have zero risk of melt down as opposed to conventional U reactors. Th reactors can also use liquid fuel which has significant advantages in operation, control and processing over solid fuels used in U reactors. Liquid fuels work at high temperature without pressurization.[7] Due to above advantages of Th, it should be heart of the most nations' atomic power effort.

2.3 New era of safe, clean and affordable energy from thorium

The use of Th-fuel cycle for nuclear power generation is a very old idea. Strongly supported by the nu-

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clear energy fathers, like A. Weinberg, E. Wigner and E. Teller, but perhaps then ultimately neglected because its intrinsic absence of military fallouts, the use of Th deserves nowadays considerable attention for emerging economies. There is a treat of climate change and there is an urgent demand for C-free energy in the World. Th fuel cycle waste has a less radiotoxic period due to absence of transuranic wastes (*i.e.* Pu, Np, Ce and Am). Th Mixed OXide (TMOX), (Pu+Th) or (U+Th) fuel can be burned in any reactor that is licensed to use Mixed OXides (MOX). There is a huge spent toxic material / Pu that has being piled up from U fuel. Th fuel can be used to safely incinerate these unwanted accumulated old stockpiles.[10]

Th produces smaller amounts of long-lived nuclear waste (TRU) than U, because it is 6 neutron captures away from ^{238}U, the entry point for the production of TRU in the neutron irradiation chain. In addition, Th has excellent physical properties such as higher melting points for both the metallic and oxide forms, and better thermal conductivity compared with U. This means that there are higher safety margins for design and operation. Most importantly, the Th-fuel cycle has the great advantage of being proliferation resistant, as the production of Pu is negligible and the U mixture in the spent fuel makes it extremely difficult to manufacture a bomb.

Three basic approaches are envisaged today in order to exploit Th: India's three stage scheme (Pu-^{233}U-Th), Feeding fresh fuel in the core like in PBMR or TMSR and using fast neutron ADSs. The last one seems to be the most efficient method.[1] Th must be used in a fast neutron flux ADS to favor breeding, to allow long burnups for better fuel usage efficiency and longer operation time and finally because TRU can fissions in a fast neutron flux, and therefore be eliminated by recycling them as fuel.

3 Problematic nuclear fuel - uranium

U is today's preferred conventional nuclear fuel in commercial reactors. U has been adequate to meet today's energy supply needs. World's U reserve is about 5.5×10^6 tons and U production is about 65×10^3 tpa. There are 19 big U producers in the World. Life expectancy of U ore is about 50-60 years. U ores are generally not harmful, but is dangerously toxic to humans if ingested, inhaled or even of prolonged contact. Conventional U reactors requires extremely rare ^{235}U (abundance: 0.7%) which must be purified/enriched from natural ^{238}U isotope. U mining, enrichment and extraction are expensive and complex as compared to Th. U fuel leaves large amount of toxic wastes containing ^{239}Pu that can be used in making bombs and weapons. The used/depleted fuel can be reprocessed by expensive Pu-U extraction (Purex) process to remove fissile material and re-fabricate new fuel elements. In the near future, R& D on U will fade away in favor of Th.[5]

4 Reactors able to use th fuel

Table 2 shows and compares U and/or Th using nuclear reactors along with fuel type, yearly cost for 1GW reactor, coolant, proliferation, waste products etc. Th, Th-MOX and MOX type fuel using reactors have significant advantages over UOX fuel using reactors. There are seven types of reactor into which Th can be used as a nuclear fuel today. Table 3 summarizes reactor and fuel types along with examples and interested counties for these reactors.[5,6]

4.1 Early research and developments on TMSR

In the 1950's, a significant Th research program led by A. Weinberg was started in the Oak Ridge National Lab in Tennessee, US. The program researched the use of Th in TMSRs, with successful and well documented results. For 20 years, Th was researched alongside U as a nuclear fuel. A 1962 report highlighted a recommendation to pursue civilian nuclear power not with U as the raw fuel but with Th However, amid lobbying by companies vested heavily in U-fed, solid-fuel, water-cooled reactors; there wasn't enough support in Congress to follow through the AEC's recommendation. In 1973, Th-related nuclear research was, however, shut down as the government chose to continue with U-based reactors only. The renewed interest in TMSRs began in 2002, when NASA scanned almost forgotten Oak Ridge National Laboratory documents detailing research on TMSRs. Table 4 shows the milestones of TMSRs.

Thor Energy is developing an advanced Th-based oxide nuclear fuel technology based on Th (Th-MOX) as an alternative to U. Th-MOX fuels maximize the utilization of Pu with high neutron moderation and maximize the cycle length for reactor fuel systems. Th-MOX (Th, Ce)O_2 pellets which were tested in the OECD's Halden LWR in Norway using rig with 6 fuel rods in 2013 and 2015. Thor Energy's fuel designs are claimed to be compatible with 90% of all existing 436 reactors (375 000 MWe in total) in operation worldwide. 90% of these are light water reactors (LWRs), these can use Th.Add and Th.MOX (http://thorenergy.no/). Thor Energy is the only company in the world that is manufacturing and qualifying Th-containing fuels for use in LWRs and is developing important intellectual property in this process. It will

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Table 2. Nuclear fuels used in U and Th reactor[4–6]

Fuel Type	UOX (U cycle)	MOX (Th Add.)	Th-Pu MOX (Supp. U cycle)	Th (^{233}U cycle)
Fissile material	3-5% ^{235}U	^{235}U	9-16%Pu (65% ^{239}Pu)	Th
Breeder material	95-97% ^{238}U	(5-10%) ^{232}Th	84-91% ^{232}Th	^{233}U
Reactors used	LWR	Seed & blanket	Can be used today's reactors	ADS, TMSR, LWR, LFTR
		Can be used today's reactors		
		ThO_2 & UO_2 rods 4.6t Th+177t U raw	Th&used Pu	Th&U fluoride sol.
Fuel	U rods	$50-60 million		1 t raw Th
1GW reactor	250 t raw U	Water		$10.000 Self regulating
Annual fuel cost	$50-60 million	None		None
Coolant	Water	200000-300000	Some	2000-3000
Proliferation potential	Medium			
Footprint (ft^2)	200000-300000			
Waste products	$^{238, 239, 240, 241}$Pu, Am, Np, Cm	$^{238, 239, 240, 241}$Pu, Am, Np, Cm	^{233}U	
Benefits	Conventional	improve fuel performance	Safety increased, waste legacy destructed	Very little long lived waste ^{233}U recycled No Pu generation

complete the 5-year qualification procedure in 2018 and plans to commence the licensing and the commercialization of Th fuels at that time.

Flibe Energy has taken the Oak Ridge TMSR work and enhanced the design into the liquid-fluoride Th reactor (LFTR), a molten-salt reactor design that can utilize Th more effectively and efficiently than ever before (http://flibe-energy.com/). Among possible reactor coolants (water, gas, metal and salt), only liquid salts offer the desirable combination of low pressure operation at high temperatures. LFTRs use liquid-fluoride salts as both a coolant and as a carrier for the Th and Th-derived fuels. LFTRs operate at near atmospheric pressure offering unmatched safety and greatly simplified reactor designs. The salts used in the LFTR are combinations of LiF-BeF_2 salts often called "F-Li-Be". Unlike current materials used in nuclear reactors, liquid FLiBe is impervious to radiation damage and incredibly chemically stable. FLiBe can hold enormous amounts of thermal energy safely and at low pressures yet at high temperatures, helping us finally realize the dream of a compact, affordable power system that can be mass-produced to meet the world's needs for power and other essential materials. Use of Th in a liquid fuel form is LFTR's key differentiator from other efforts to employ Th as a nuclear fuel.

In S. Africa, Steenkampskraal Thorium Limited (STL) spends most of its time and resources working on the design of its small modular pebble-bed reactor (PBMR), the HTMR-100. This nuclear plant power source is a 100 MW high temperature He cooled PBMR. It features a Once-Through-Then-Out (OTTO) fuel cycle. The reactor is versatile enough to accommodate various types of fuelling schemes such as the U, U/Th or Pu/Th based fuel cycles. Fully ceramic coated fuel elements (TRISO) effectively retaining the fission products within the fuel, allowing for high burnup and preventing melting even in extreme accidents which may result in the total loss of active core cooling. The company makes progress with the overall reactor design and with the designs of several important components, including the core structures, the reactor pressure vessel, the steam generator, the double-set isolation valves and the fuel loading and unloading devices. The company prepares a detailed project plan and a schedule to proceed to a generic design assessment. The company also makes progress with its design of a pebble press laboratory to produce fuel spheres. Preliminary discussions have been held with the National Nuclear Regulator about the licensing of MPBR design. STL owns 12.5% of Thor Energy in Norway (http://www.thorium 100.com/).

According to Colorado School of Mines 2014 report, STL's Steenkampskraal mine in South Africa is the lowest cost producer of Th in the world, with an estimated

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Table 3. Reactors able to use Th fuel[8–10]

Reactor Types, Examples and Interested Countries	Fuel Types
Heavy Water Reactors (PHWR) (Candu, NRX, NRU reactors of AECL ' s Chalk River Laboratories; 300 MWe Indian AHWR; Qinshan Phase III, China) (Canada, China and India are interested)	Very flexible to switch between U and Th based fuels without extensive modifications. ThO_2, mixed ThO_2-UO_2 (both LEU and HEU) and mixed ThO_2-PuO_2 fuels are tested (LEU: low enriched and HEU: high enriched uranium).
High Temperature Gas-Cooled Reactors (HTR) (300 MWe AVR German THTR; 40MWe Peach Bottom HTR, USA; 330 MWe Fort St. Vrain HTR, USA, 20 MWe Dragon, UK) (The UK, Germany, Austria, Denmark, Sweden, Norway and Switzerland are interested)	TRISO coated particles of Th mixed with Pu/HEU. Th fuels can be designed for both "Pebble bed" and "Prismatic" HTR fuel varieties. Almost microscopic size small particles of Th plus U are coated with 3 layers of pyrolytic C and SiC then heated in a kiln to form a TRISO coated particle.
Boiling (Light) Water Reactors (BWR/LWR) (Shippingport, USA, 60 MWe Lingen, Germany BWR)	Th-Pu fuel rods, Th+LEU, Th+^{233}U
Pressurized (Light) Water Reactors (PWR) (Radkowsky Th Reactor; Angra-1 PWR, Brazil, VVER, Russia, Obrigheim PWR, EU) (Germany, Brazil, Russia and EU are interested)	Heterogeneous "seed-blanket" Th fuel arrangement
Fast Neutron Reactors (FNR)	Th fuel has little or no competitive edge in these systems.
Molten Salt Reactors (MSR)/Liquid Fluoride Thorium Reactors (LFTR) (The Oak Ridge National laboratory, USA; 5 MWe TMSR, SINAP, China) (China, Japan, Russia, France and the USA are interested)	Well suited for Th fuel use. Unique fluid fuel incorporates Th and U fluorides as a part of a salt mixture (Li-Be) that melts in the range of 400-600 °C and these liquids serve as both heat transfer fluid and the matrix for the fissioning fuel. Novel designs, but implementation and licensing may take a decade.
Accelerator Driven Reactors (ADS/ADR) (ADTR, UK)	Spallation neutrons are produced when high energy protons from an accelerator strike a heavy lead target. These neutrons are directed to Th-Pu fuel.

production cost of 3.56 $/kg. The second cheapest producer has an estimated production cost of 7.98 $/kg and the third cheapest a production cost of 8.01 $/kg. The report indicates that the three lowest cost producers could together produce about 3,718 tons of Th per year, which is about the quantity that the report indicates could be required by the nuclear industry in the future (http://www.thorium100.com).

5 Conclusions

There are safe methods of using Th with no risk for meltdown or explosions. Th energy is also proliferation resistant. Th reactors create zero-emission energy. The amount of waste is low both in amount and lifetime. Th is one of the most energy-dense elements in nature, found in great quantities on all continents. Th itself generates essentially no Pu, and no minor actinides as it burns unlike U fuel. There is more Th energy available than in all oil, gas, coal and U on Earth combined. Research into the use of Th energy started in the 1950's in the US Oak Ridge atomic lab, with successful and well-documented results.

Achieving more sustainable energy generation in which mined nuclear material is used more effectively. This draws on the possibility for high conversion and eventually breeding of fissile ^{233}U from Th fuels. Employing fuels that generate less problematic waste streams, and that can also transmute (destroy) actinide components in current-generation thermal reactor systems.

Liquid fueled Th reactors are safer, simpler, more fuel efficient, more proliferation resistant, less waste generator and require lower initial capital costs and construction than solid fueled conventional reactors. ADS with Th fuel offer the possibility to destroy a major part of the long-lived waste inventory to reduce the need for long-term storage, while at the same time producing energy. For energy production, there would be synergy between renewable and Th ADS, as the power from ADS can be

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Table 4. Developments on TMSRs[8–10]

Year	Development on TMSRs
1950 1973	Dr. Alvin Weinberg discovery of MSR in Oak Ridge Lab in the US.
1990s	The first phase ADS-1 development at CERN
2000s	ADS-2 proton beam exceeded a power of 1 MW
2006	Thor Energy-Norway is established and Th fuel strategy starts.
2008	Google Tech Talks on Thorium
2011	China announces national TMSR program Flibe Energy is founded by K. Sorensen International Thorium Irradiation Consortium (ITIC) established (Thor Energy, Westinghouse, Fortum, IET and Rhodia)
2012	Thor Energy starts to develop Th based fuel pellets.
2013	First Th irradiation tests at Halden reactor by ITIC. India starts working on two TMSR designs (BARC).
2015	Bill Gates Terra Power starts MSR work Indonesia starts working on TMSR with ThorCon S. Korea joint to ITIC. Second Th irradiation tests at Halden reactor by ITC.
2016	IAEA to create platform for international TMSR cooperation
Until 2032	ADS-3 phase (Linear accelerators (MYRRHA (EU), ADANES (China) and HISPA (India) (high power proton linac.

modulated to follow the fluctuations of wind and solar energies. Th is sustainable, reliable and economical energy source. The author expects to see safe and small ADS and/or MSR Th reactors on the market in 10 years.

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